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Atmospheric Infrared Sounder (AIRS)

Visible and Infrared In-Flight Calibration Plan

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1 Introduction

1.1 Identification

This In-Flight Calibration Plan describes the process of calibrating and tracking the performance of the Atmospheric Infrared Sounder (AIRS) instrument during in-flight operations. Calibration makes use of special tests to be performed in orbit, Level 1B Quality Assessment (QA) Indicators, and Earth Scene data products. This document will be used by the AIRS instrument calibration team to develop procedures and software to be used in determining the instrument performance, calibration, and overall health and status during flight operations. The document will also be used by the flight operations team to assist in defining calibration operations during the activation and evaluation phases and during the normal instrument operations phase.

1.2 Document Scope

This document defines the requirements for the in-flight calibration program and the corresponding ground-data evaluation effort. The document also defines requirements for post processing of Level 1B QA indicators and Earth Scene calibration data products and special tests procedures for unique tests to be performed in orbit and at TRW. These tests will be used to verify that the AIRS instrument is stable and calibrated and to verify that the Level 1B algorithms and software are working properly.

This document will allow the calibration team to identify additional software required to evaluate instrument calibration (above and beyond the Level 1B and Level 2 processing software). Any necessary changes to the Level 1B data product, algorithms, or lookup tables will be reflected in the Level 1B ATBD (Reference 2) and/or the L1B Interface Specifications (Reference 6), as appropriate. This document also identifies the top-level procedures for special calibration tests to be performed during in-orbit checkout (activation and evaluation) and during routine maintenance calibration periods. The document discusses high-rate telemetry monitoring and the Earth Scene calibration program.

1.3 Document Structure

Section 1 provides AIRS background and an overall approach for calibration. The subsequent sections discuss each of the major elements of the calibration approach, as follows:

- Section 2, Use of Pre-Flight Calibration Data, identifies which of the pre-flight calibration data sets are key to the in-orbit calibration.
- Section 3, In-Flight Special Test Procedures for Calibration, defines the requirements for the special test sequence procedures and details how the data are to be flagged.
- Section 4, Post Processing of L1B Quality Assessment (QA) Data, discusses the requirements for post processing of the Level 1B QA indicators leading to the monitoring and trending of key calibration indicators in flight.
- Section 5, Telemetry Monitoring Plan, presents the plan for monitoring and trending the AIRS engineering telemetry to detect anomalous behavior in the instrument operation, performance, or calibration.
- Section 6, Use of Earth Scene Data for Calibration, discusses how we intend to use the Earth Scene to verify our instrument calibration. This involves spatial, spectral, and radiometric analyses of varying Earth Scene targets.

- Section 7, In-Flight Calibration Operations Requirements, presents data expedite requirements and the requirements to the operations team for sequencing special tests.
- Section 8, Timeline for Calibration, presents our plan for when special tests and routine monitoring are to take place.

1.4 AIRS Background

The National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) is a spaceborne global observation system designed to obtain comprehensive long-term measurements to help understand Earth processes affecting global change. AIRS is a key facility instrument on Aqua, the first PM (1:30 pm Equatorial Crossing Time) EOS platform. AIRS is designed to provide both new and more accurate data — compared to previous instruments — regarding the atmosphere, land, and oceans. This data will be used in climate studies and weather prediction. Among the important parameters to be derived from AIRS observations are atmospheric temperature and humidity profiles and ocean and land surface temperatures.

The AIRS instrument is the first hyperspectral infrared sounder developed by NASA in support of operational weather forecasting by the National Oceanic and Atmospheric Administration (NOAA). Integration of the fully tested and calibrated AIRS flight unit with the EOS Aqua satellite started in December 1999, with the launch scheduled for year 2001.

1.4.1 AIRS Mission Overview

Requirements for atmospheric sounding were first established in the late 1950s. Since the late 70s, NOAA polar orbiting satellite systems have supported operational weather forecasting with the High Resolution Infrared Sounder (HIRS) and the Microwave Sounding Unit (MSU) derived global temperature and moisture soundings. In 1987, after analyzing the impact of the first ten years of HIRS/MSU data on weather forecasting accuracy, the World Meteorological Organization (WMO) determined that significantly improving weather forecasting would require global temperature and moisture soundings with radiosonde accuracy.

Radiosonde accuracy is equivalent to profiles with 1-K rms accuracy in 1-km thick layers and humidity profiles with 10% accuracy in the troposphere. To meet the WMO requirements, an extensive data simulation and retrieval algorithm development effort was required to establish instrument-measurement requirements in the areas of spectral coverage, resolution, calibration, stability, and spatial response characteristics, including alignment, uniformity, and measurement simultaneity, radiometric and photometric calibration and sensitivity. The 1-K/1-km requirements can only be met by increasing the spectral resolution of the infrared sounder by approximately one order of magnitude, from the $\lambda/\Delta\lambda = 100$ resolving power of HIRS-2 to the hyperspectral $\lambda/\Delta\lambda = 1200$ resolving power of AIRS. Sensitivity requirements, expressed as Noise Equivalent Differential Temperature (NEdT), referred to a 250-K target-temperature, range from 0.14 K in the critical 4.2-μm lower tropospheric sounding wavelengths to 0.35 K in the 15-μm upper tropospheric sounding region. These requirements are captured in the AIRS Functional Requirements Document (FRD), which governed the design and development of the instrument.

AIRS, with spectral coverage from 3.7 to 15.4 μm, the Advanced Microwave Sounding Unit (AMSU, 27 to 89 GHz), and the Microwave Humidity Sounder (HSB, 150 to 187G Hz) form a complementary sounding system for NASA's Earth Observing System (EOS) Aqua spacecraft. EOS Aqua is designed by NASA to support the operational weather forecasting effort of NOAA.

The AIRS instrument (shown in Figure 1) incorporates numerous advances in infrared sensing technology to achieve a high level of measurement sensitivity, precision, and accuracy. This includes a temperature controlled grating spectrometer operating at 140 K, long wavelength cutoff HgCdTe infrared detectors, and an active pulse tube cryogenic cooler operating at approximately 60 K.

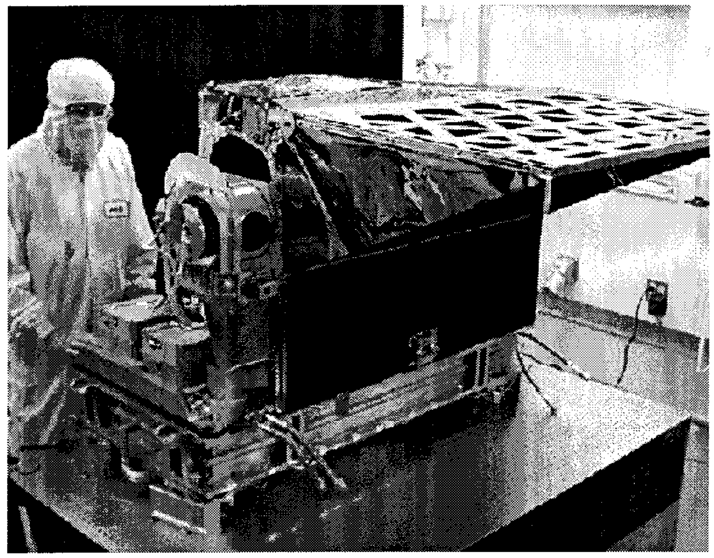


Figure 1. The Atmospheric Infrared Sounder (AIRS).

Full use of the high measurement sensitivity and accuracy capability of AIRS requires very careful pre-launch calibration complemented by routine in-flight monitoring. The extensive pre-launch spectral, spatial, and radiometric calibration of AIRS was made using a test facility located at the BAE SYSTEMS facility in Lexington, Massachusetts, and designed specially for AIRS.

1.4.2 Instrument Overview

The AIRS Instrument provides spectral coverage in the 3.74- to 4.61-µm, 6.20- to 8.22-µm, and 8.8- to 15.4-µm infrared wavebands at a nominal spectral resolution of $\lambda/\Delta\lambda = 1200$, with 2378 IR spectral samples. A cross section of the scan head assembly is shown in Figure 2. A 360-degree rotation of the scan mirror generates a scan line of IR data every 2.667 seconds. The scan mirror motor has two speeds:

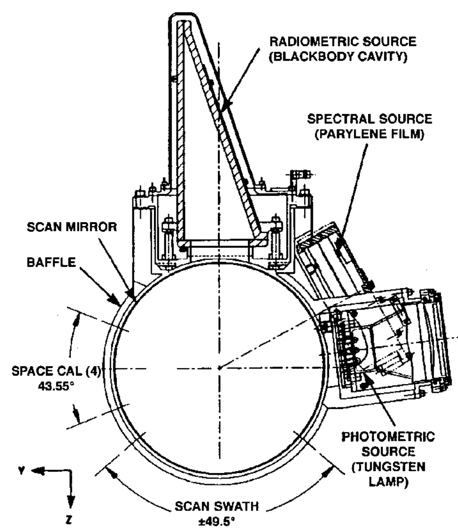


Figure 2. AIRS Scan Assembly.

- During the first two seconds, the mirror rotates at 49.5 degrees/second, generating a scan line with 90 footprints of the Earth Scene, each with a 1.1-degree diameter Instantaneous Field of View (IFOV).
- During the remaining 0.667 seconds, the scan mirror completes one complete revolution, with four independent views of cold space, one view into a 310 K radiometric calibrator (the On-Board Calibrator [OBC] blackbody), one view into a spectral reference source (Parylene), and one view into a photometric calibrator.

The VIS/NIR photometer, which contains four spectral bands, each with nine pixels along track, with a 0.185-degree IFOV, is bore sighted to the IR spectrometer to allow simultaneous visible and infrared scene measurements.

The diffraction grating in the IR spectrometer disperses the radiation onto 17 linear arrays of HgCdTe detectors (see Figure 3) in grating orders 3 through 11. Fifteen of the seventeen linear arrays are comprised of **N** elements by two rows (A and B) for redundancy. The number of elements per array, N, is shown in Table 1. The IR spectrometer is cooled to 150 K by a two-stage radiative cooler.

The IR focal plane is cooled to 60 K by a Stirling/pulse tube cryocooler. The scan mirror operates at approximately 265 K due to radiative coupling to the Earth and space and to the 150-K IR spectrometer. Cooling of the IR optics and detectors is necessary to achieve the required instrument sensitivity. The VIS/NIR photometer uses optical filters to define four spectral bands in the 400- to 1000-nm region. The VIS/NIR detectors are not cooled and operate in the 293- to 300-K ambient temperature range of the instrument's scan head housing.

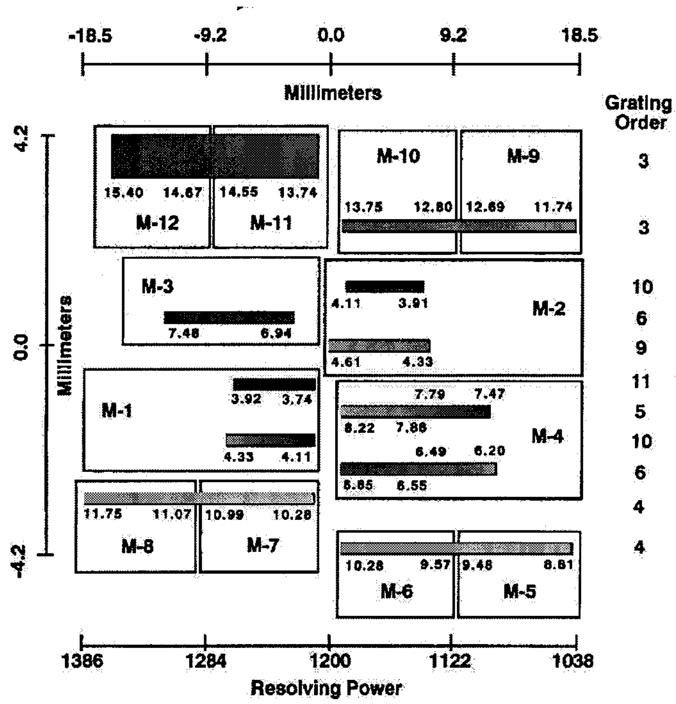


Figure 3. AIRS FPA Layout.

Signals from both the IR spectrometer and the VIS/NIR photometer are passed through onboard signal and data processing electronics, which perform functions of radiation circumvention, gain ranging and offset subtraction, signal integration, and output formatting and buffering to the high-rate science data bus. In addition, the AIRS instrument contains command and control electronics whose functions include communications with the satellite platform, instrument redundancy reconfiguration, the generation of timing and control signals necessary for instrument operation, and collection of instrument engineering and housekeeping data.

The Stirling/pulse tube cryocoolers are driven by separate electronics that control the phase and amplitude of the compressor moving elements to minimize vibration and to accurately control the temperature. Heat from the electronics is removed through coldplates connected to the spacecraft's heat-rejection system.

Table 1 provides essential information to identify each detector and module. This includes the module numbers, the module type and name, the spectral range, the quantization level, and the number of samples in each module. Table 1 also gives the readout order, the channel identification in the Ground Support System (GSS) numbering scheme, and the L2 science processing numbering scheme.

An additional description of the AIRS instrument is provided in the AIRS calibration plan (Reference 1), and the AIRS Level 1B ATBDs (References 2 and 3).

Table 1. Detector and Module Identification Information.

Array Number	Array Type	Array Name	ROIC Channel	Spectral Cuton µm	Spectral Cutoff µm	Num Bits per Sample	Num Samples	ROIC First Detector Read Out	ROIC Last Detector Read Out	GSS Channel Start	GSS Channel End	L2 Ch Start	L2 Ch Stop
1	PV	M1A	R01S	3.7364	3.9169	14	118	118	1	0	117	2378	2261
2		M1B	R01L	4.11	4.3291	14	130	130	1	118	247	2144	2015
3		M2A	R02S	3.9149	4.11	14	116	1	116	248	363	2260	2145
4		M2B	R02L	4.3271	4.6085	14	150	1	150	364	513	2014	1865
5		M3	R03X	6.9356	7.4769	13	192	192	1	514	705	1654	1463
6		M4A	R04S	6.2003	6.4934	13	104	1	104	706	809	1864	1761
7		M4B		6.5504	6.85	13	106	1	106	810	915	1760	1655
8		M4C	R04L	7.4745	7.7921	13	94	1	94	916	1,009	1462	1369
9		M4D		7.8605	8.22	13	106	1	106	1,010	1,115	1368	1263
10		M5	R05X	8.8073	9.4796	13	159	159	1	1,116	1,274	1262	1104
11		M6	R06X	9.565	10.275	13	167	167	1	1,275	1,441	1103	937
12		M7	R07X	10.275	10.985	13	167	167	1	1,442	1,608	936	770
13		M8	R08X	11.0704	11.7512	12	161	161	1	1,609	1,769	769	609
14		M9	R09X	11.7431	12.685	12	167	1	167	1,770	1,936	608	442
15		M10	R10X	12.7989	13.7457	12	167	1	167	1,937	2,103	441	275
16	PC	M11	R11	13.7377	14.5533	12	144	1	144	2,104	2,247	274	131
17		M12	R12	14.6672	15.4	12	130	1	130	2,248	2,377	130	1
18	Vis/NIR	VIS1	Vis/NIR	0.41	0.44	12	72	1, 5, 9,	... 285	2,378	2,449	-	-
19		VIS2		0.58	0.68	12	72	2, 6, 10,	... 286	2,450	2,521	-	-
20		VIS3		0.71	0.92	12	72	3, 7, 11,	... 287	2,522	2,593	-	-
21		VIS4		0.49	0.94	12	72	4, 8, 12,	... 288	2,594	2,665	-	-

Notes:

Total Number of Detector Samples: 2666

Number of 16-bit Packed Words of Packetized data: 2133

Vis/NIR has 4 channels (colors). After reordering the SEM/ROIC output, each channel has 72 values per footprint = 9 spatial detectors per footprint along track x 8 temporal samples per footprint across track.

The 72 are ordered: d0, s0; d1, s0; d2, s0; ... d6, s7; d7, s7; d8, s7

Max value per sample (2**12)-1 = 4095 (unnormalized) (2**13)-1 = 8191 (2**14)-1 = 16383

1.5 Approach for Calibration

Figure 4 shows the steps required for in-flight calibration of the AIRS instrument. The process starts with the pre-flight calibration performed at the instrument development facility at BAE Systems.

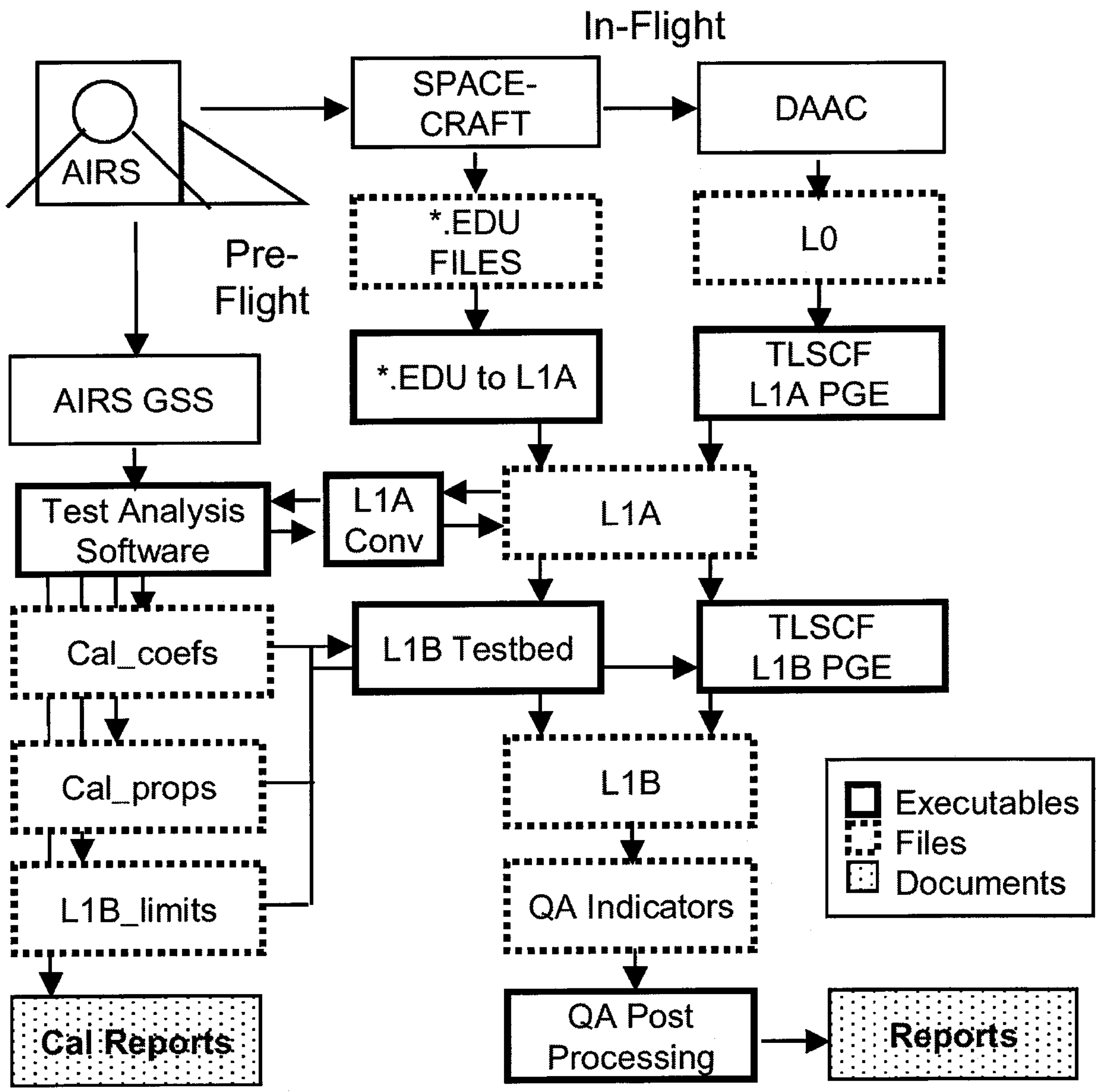


Figure 4. Process for validating the L1B calibration involves special tests, a testbed, monitoring of QA indicators and validation of the calibration by the science team.

Analyses are performed on these data to arrive at calibration coefficients and calibration properties. The coefficients are used for radiometric and spectral calibration of the Level 1B data product. The properties are not used in the calibration but characterize the performance of the instrument and include spectral centroids and bandwidths, noise performance indicators, spatial centroids and A/B weights for all the channels. The calibration coefficients and calibration properties are discussed in Section 2.

A set of "special" tests have been defined to determine AIRS performance with the internal calibrators and views to space. The special tests are defined in Section 3. Results from the special tests are used to update the calibration properties and report on calibration anomalies. The types of parameters evaluated by the special test include coarse spectral centroid (using the Parylene), gain and noise characteristics, stray light, and radiation sensitivity.

The special tests will first be run using flight procedures during testing at TRW. Figure 4 shows the data flow during testing. There are two possible paths. The first path uses the AIRS Ground Support System (GSS). This is a copy of the system that was used for testing during AIRS development at BAE SYSTEMS. During flight operations, we will not be able to use this system and will need to rely on the Level 1A data. This path is depicted in the right of Figure 4. Data passes to the Distributed Active Archive Center (DAAC) and is converted to Level 0. The data is then sent to JPL where it is to be converted to Level 1A prior to processing by the calibration team. We have developed an L1A converter; therefore, we do not need to reprogram the interface to the special test software. The tool also to converts the GSS data into Level 1A. If the GSS is not working at TRW, we have a backup source of data and can receive solid-state recorder files in a special *.EDU format. A program has also been developed to convert these to L1A that can then be translated into the test analysis format.

The most essential element of the calibration is the proper implementation of the L1B software. The L1B software produces calibrated radiances and a complete set of QA indicators. The AIRS calibration team is responsible for the accuracy of the L1B product and, therefore, has developed techniques for monitoring its performance. First we have developed a Level 1B testbed. This is where we test the calibration algorithms in a testbed environment. The L1B algorithms are coded here first, prior to implementation by the Product Generation System (PGS). The results are evaluated for accuracy by running the L1B on pre-flight data sets acquired in thermal vacuum at BAE. The algorithms that go into the L1B data product and the results of testing the L1B testbed are provided in Reference 6.

Routine monitoring of the L1B QA indicators is a critical element of the in-flight calibration. We have implemented QA algorithms in the Level 1B to monitor items critical to the calibration. These include gain and noise statistics, offset and drift, and spectral stability. A complete list of the QA indicators is provided in the L1B Requirements (Reference 6). The QA indicators are processed by special software. This software is not intended for operational use at the DAAC during the first year of AIRS flight operation. Output of the analyses will be trend reports of the major calibration and performance indicators. Trending will be performed over orbital, seasonal, and annual timescales.

Trending and monitoring is also performed on the instrument telemetry. This document summarizes the plan for monitoring critical telemetry as it relates to the performance and calibration of the AIRS instrument, including cooler operation, instrument temperatures, electronics supply and reference voltages, and scanner stability. Health and safety monitoring is primarily performed by the operations team by monitoring the real-time, low-rate engineering data. The job of the in-flight calibration team will be to monitor the high-rate engineering data and trend the engineering telemetry; this is not possible in real time and, as such, is less effective as a safety measure. The data will be useful for identifying long-term trends in instrument operation.

A final key element in the calibration plan is the Earth Scene validation program. During the first few months of AIRS operation, the Earth Scene will be used to detect anomalous systematic calibration errors in the spatial, radiometric, and spectral performance of AIRS. This initial calibration will be followed by the regular AIRS validation program, as discussed in Reference 5.

1.6 References

The following documents are referenced within this calibration plan and/or are applicable to the plans and procedures contained herein.

1. "AIRS Instrument Calibration Plan," H. Aumann, K. Overoye, JPL D-16821, Preliminary, November 14, 1997
2. "AIRS Level 1b Algorithm Theoretical Basis Document (ATBD) Part 1 (IR)," H. Aumann et al., December 15, 1999
3. "AIRS Level 1b Algorithm Theoretical Basis Document (ATBD) Part 2 (VIS/NIR)," M. Hofstadter et al., December 15, 1999
4. "Telemetry/Calibration Handbook," V.7, Lockheed Martin Infrared Imaging Systems, JPL, JPL-D-16920, July 26, 1999
5. "AIRS Validation Plan," Version 2.0, E. Fetzer (Editor), JPL D-16822, December 20, 1999
6. "Atmospheric Infrared Sounder (AIRS) Level 1B Infrared Algorithm and Quality Assessment (QA) Processing Requirements," T. Pagano and S. Gaiser (to be published)
7. "AIRS Product Generation System (PGS)," Requirements and Design Document, V1.0, December 1988
8. "AIRS Special Calibration Test Processing Procedures," (to be published)
9. "AP-15: Ambient Comprehensive Performance Test (CPT) #1," J. Gohlke and G. Goodson, JPL Procedure AIRS 230, Draft 3, March 23, 2000
10. "AIRS Pre-Flight Testing Data Book," (to be published)
11. "Pre-Launch Performance Characteristics of the Atmospheric Infrared Sounder," T. Pagano et al., SPIE 4169-41, September 2000
12. "AMA Operational Characteristics and Constraints," W. Shaw, DFN 99172, 4 June 1999.
13. "Recommended Changes to AMA Equations Based on PFM Test Data," M. Weiler, DFN200001, 28 February 2000, and "Recommended Changes to AMA Equations Based On PFM Test Data – Revision to DFN200001" dated 27 June 2000, DFN number 200015
14. "AIRS AMA Operations Manual," R. Schneider, RS-781-00-008, October 30, 2000
15. "Evaluation of CERES scanner pointing accuracy using a coastline detection system" C. Currey, L. Smith, and B. Neeley, SPIE 3438, 367, 1998
16. "Atmospheric Infrared Sounder Quality Assessment Plan," E. Fetzer editor, Volume 20 (to be published)

2 Use of Pre-Flight Calibration Data

This section provides references to other documents that provide the details regarding the pre-flight calibration program. These documents are readily available on the AIRS Calibration Web site, www-airs.jpl.nasa.gov. The documents can also be obtained by contacting the AIRS project office directly.

The AIRS [Pre-Flight] Instrument Calibration Plan, Reference 1, discusses the sources and setups used in the pre-flight calibration. The document was developed early in the program and may have some obsolete data. A newer reference for an overview of the "as measured" performance is Reference 11. This paper provides test results as determined at the end of the pre-flight calibration program. A more comprehensive and detailed account of the pre-flight testing program is provided in Reference 10, the AIRS Pre-Launch Testing Data Book. This document is a compilation of many reports for each of the tests performed at BAE SYSTEMS and includes an overview of the test program.

Calibration coefficients — including the zeroth, first, and second order coefficients and corrections for radiometry, the scan angle dependent polarization correction terms, the spectral response functions, and channeling corrections — are available on the AIRS Calibration Web site. Documentation is available in the corresponding directories. In particular, AIRS Design File Memos, ADF-486 and 487 define the radiometric calibration coefficients. These calibration coefficients are critical to the success of the calibration program and are, therefore, carefully documented as to how they were obtained.

A calibration-properties file has been developed that identifies AIRS key performance indicators. Table 2 identifies the properties that are to be tracked in the calibration properties file.

Table 2. Calibration Properties for AIRS give key performance indicators.

Column	Name	Description
1	LMID	Standard channel identifies as used by BAE SYSTEMS during T/V testing. First channel is 0, last is 2377.
2	L2ID	Re-numbering based on increasing wave number. Some overlap.
3	*Vc*	Spectral Centroid (cm^{-1}).
4	d*V*	Spectral Width (cm^{-1}).
5	Q_spec	Spectral Quality Indicator. 1 = good, 2 = OK but some problems, 3 = poor, 4 = useless.
6	NEdT(K)	NEdTs per channel as obtained while viewing OBC BB during guard tests, normalized to 250 K.
7	N>4sig	Number of events greater than 4 sigma encountered in 30000 points. Any channel having greater than 8 is Non-Gaussian.
8	pops	Number of "pops", encountered in 30,000 points.
9	resid(K)	Residual radiometric error encountered at 40 degree scan angle during T/V testing.
10	PF	AIRS polarization factor.
11	Azcent(deg)	Azimuth Spatial Centroids.
12	Elcent(deg)	Elevation Spatial Centroids.
13	AB_State	Defines whether A, B or Both detectors are used in the Gain Table

These properties were selected due to their implications on the performance of the Level 2 data product. The properties include spectral centroid and width, spectral quality, Noise Equivalent differential Temperature (NEdT) per channel and noise indicators. Residual calibration error is presented from the pre-flight testing program. Spatial azimuth and elevation centroids are presented for every pixel as well as the selection of A, B, or A&B usage of the AIRS detectors in the final output product. Any channel without both A and B operational may have greater calibration errors. A complete description of the calibration properties file is provided in ADF-485. The calibration properties are also available on the AIRS Calibration Web site along with the ADF-485 documentation.

3 In-Flight Special Tests Procedures for Calibration

This section defines procedures for the special tests to be performed during the in-orbit operations of the AIRS instrument. The tests are also to be performed at TRW during instrument checkout and thermal vacuum to verify our ability to command the instrument into the correct configuration for tests and to provide a baseline set of measurements that we can compare to the in-flight test results. The tests are structured to provide the best spatial, radiometric, and spectral information possible using internal calibration sources and instrument telemetry. The purpose of this testing is twofold: first, to verify the calibration coefficients and characteristics determined pre-flight are still valid in the in-orbit environment and, second, to identify any new sources of noise or stray light. All special tests process the Level 1A data product. Data from the special tests are to be expedited to allow rapid turnaround of the results to the operations and science team.

3.1 Overview

Table 3 identifies the special tests. Tests are given an ID with designation AIRS-CX, where X ranges from 1 to 12 and identifies the test. A brief description of each test is provided in the table.

Table 3. AIRS Special Test Procedures to support calibration.

Test ID	Name	Description
AIRS-C1	Normal Mode / Special Events	Establish normal DCR and Lamp operation. Flag data for special events such as spacecraft maneuvers and Earth Scene targets of opportunity.
AIRS-C2	Guard Test	Cycles through A, B and A/B Optimum Gains and acquires data.
AIRS-C3	Channel Spectra Phase	Heat and cool spectrometer by ±1K to shift the channel spectra from the entrance filters. Gain data obtained is used to determine channel spectra phase.
AIRS-C4	AMA Adjust	AMA is moved to the desired x (spatial) and y (spectral) position.
AIRS-C5	OBC Cool	Blackbody heater is turned off. Data obtained during the cool down allows determination of the instrument non-linearity.
AIRS-C6	Variable Integration Time	Integration time is varied on readout while scanning. This gives a measure of the electronics non-linearity that can be trended over time.
AIRS-C7	Space View Noise	The scan mirror is stopped and parked at either the space view or the OBC BB with different A, B and AB optimum gains. Allows noise characterization.
AIRS-C8	Radiation Circumvention	Same test as AIRS-C7 but with radiation circumvention turned on. Allows determination of the effectiveness of the radiation circumvention circuitry.
AIRS-C9	Scan Profile	The AIRS nominal scan profile is rotated to allow the slow part of the scan to view either the space view or the combined OBC/Parylene view. Allows characterization of any stray light sources.
AIRS-C10	Lamp Operations	Each of the three lamps are exercised by user command.
AIRS-C11	Warm Functional	A test pattern is run through the electronics to verify data packet integrity. Another subtest cycles the power on each of the focal planes to establish functionality.
AIRS-C12	Cold Functional	Same as AIRS-C11 except performed cold. This allows more accurate characterization for the focal plane subtest.

3.2 Special Test Timeline

The timeline for special tests at TRW and in orbit is shown in Table 4. The details of the test procedures are provided in Section s3.5 through 3.16. The entire list of special tests in the table are to be run at each of the hot and cold plateaus in thermal vacuum and during the checkout phase of the in-orbit activation. A time has been allocated for each test as expected for flight operations. Most do not reflect the actual run time of the test; instead, the times reflect an estimate of how long it would take to prepare for the test, execute it, and transition to the next test. The tests are divided into seven functional groups. All tests within a group must be performed without a change of instrument state. We constrain the sequence of the tests and the stability requirements.

Group 1: The first testing must be performed while the instrument is not yet cold. Group 1 in the table reflects this condition. At this time, we perform the Warm Functional tests, AIRS-C11. This involves the warm focal plane Functionality test and the Test Pattern test. We also run AIRS-C10 for all three lamps, where the lamps are on for one full orbit.

Group 2: This group is performed when AIRS is almost cold; that is, 170 to 155 K. This may be the same day as Group 1, but is separated here for clarity. At this time, we run the Cold Functional tests (AIRS-C12) to verify FPA operations. Then we run AIRS-C1 (normal mode) operations several times as we are cooling down, preferably every 3 degrees, but most likely whenever we have an opportunity.

Group 3: This group is performed when we have reached 155 K, but are not fully stabilized. At this point we run a Normal Mode acquisition, AIRS-C1, to establish a baseline. We then run the full Guard test, AIRS-C2. This will allow us to acquire gain and sensitivity data for all detectors. We follow the Guard test with the complete set of SV Noise tests, AIRS-C7, to acquire noise statistics. Data from AIRS-C2 and AIRS-C7 are used to develop a new A/B optimum list and Circumvention Levels that will be used to update the gain table.

*****At this time we update the AIRS Gain and Circumvention table*****

Group 4: Prior to acquisition of calibration data, the Adjustable Mirror Assembly (AMA) needs to be aligned. This involves first running the Guard test, AIRS-C2. (This test should be run every day while cold.) The A/B data is used to determine the AMA move. We then run AIRS-C4, the AMA Adjust test, and then re-run the Guard test, AIRS-C2, to check our move. While we are waiting for data from the move to be analyzed, the operations team runs the Scan Profile test, AIRS-C9. This test does not require good radiometry, but is necessary to characterize the registration with the calibration targets and stray light in the space viewport. Next, the Variable Integration Time test, AIRS-C6, is run. Following AIRS-C6, we re-run the AMA alignment procedure, AIRS-C4, if necessary, followed by AIRS-C2 to check our results.

Group 5: At the start of Group 5, we must again run the Guard Test. We then need to optimize and understand the radiation circumvention process. At this point we will have calculated new Circumvention Levels from the AIRS-C7 test performed on Group 3. AIRS-C8 loads the new Circumvention Levels and re-runs AIRS-C7. We then look at how well the new circumvention table works. We re-calculate the Circumvention Levels and update the gain table.

*****At this time we update the AIRS Gain and Circumvention table*****

We have allowed a re-run of AIRS-C7 with the new Gain and Circumvention table to verify circumvention performance.

Table 4. Special Test Procedures Sequence.

Sequence	Test ID	Phase	Name	Duration (hrs)	Description
Group 1	**Warm Functional**				
> 170 K	AIRS-C11	1	Warm Funct	4	Focal Plane Functionality Test
	AIRS-C11	2	Warm Funct	3	Test Pattern
	AIRS-C10	1	VIS/NIR Radiom.	4	Lamp 1
	AIRS-C10	2	VIS/NIR Radiom.	4	Lamp 2
	AIRS-C10	3	VIS/NIR Radiom.	4	Lamp 3
Group 2	**Cold Functional + Cooldown Acquisitions**				
170 K	AIRS-C12	1	Cold Funct	4	Focal Plane Functionality Test
	AIRS-C12	2	Cold Funct	3	Test Pattern
	AIRS-C1	0	Normal Mode	1	Special Event Data Acquisitions
Group 3	**Pre-AMA Adjust Baseline**				
≈155 K Pre-Stable	AIRS-C1	0	Normal Mode	1	Special Event Data Acquisitions
	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_1
	AIRS-C7	2	SV Noise	2	A Space
	AIRS-C7	3	SV Noise	2	B Space
	AIRS-C7	4	SV Noise	2	AB, Space
	AIRS-C7	5	SV Noise	2	A OBC
	AIRS-C7	6	SV Noise	2	B OBC, Calc A/B_2
Group 4	**Adjust AMA + Scan Profile**				
155 K Stable	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_2
	AIRS-C4	0 - 2	AMA Adjust	6	First AMA Adjust
	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_2
	AIRS-C9	1	Scan Profile	1	Nadir Profile
	AIRS-C9	2	Scan Profile	1	Space Profile
	AIRS-C9	3	Scan Profile	1	OBC/Parylene Profile
	AIRS-C6	0 - 7	Variable Integ. Tm	2	Integration Time Test
	AIRS-C4	0 - 2	AMA Adjust	6	Second AMA Adjust (If Req'd)
	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_2
Group 5	**Radiation Circumvention Adjust**				
155 K Stable	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_2
	AIRS-C8	5	Rad Circ	4	A OBC: Rad Circ. On
	AIRS-C8	6	Rad Circ	2	B OBC
	AIRS-C8	4	Rad Circ	2	A/B_2 OBC, Calc A/B_3
	AIRS-C8	5	Rad Circ	4	A OBC: Rad Circ. Repeat
	AIRS-C8	6	Rad Circ	2	B OBC
	AIRS-C8	4	Rad Circ	2	A/B_3 Space
Group 6	**OBC Float**				
155 K Stable	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_3
	AIRS-C5	1	OBC Float	1	Nom Temp, Initial
	AIRS-C5	2	OBC Float	12	Cooldown Acquisitions
	AIRS-C5	3	OBC Float	6	Warmup Acquisitions
Group 7	**Channel Spectra Phase + VIS/NIR**				
155 K ± 1 K Stable	AIRS-C2	0 - 7	Guard Test	2	Cycle Through Gains: A, B, A/B_3
	AIRS-C3	3	Channel Phase Test	8	Nom Temp, Initial, incl. Transition

Sequence	Test ID	Phase	Name	Duration (hrs)	Description
	AIRS-C3	1	Channel Phase Test	16	High Temp, incl. Transition
	AIRS-C3	2	Channel Phase Test	8	Low Temp, incl. Transition
	AIRS-C3	1	Channel Phase Test	1	Nom Temp, Final
	AIRS-C10	1	VIS/NIR Radiom.	4	Lamp 1
	AIRS-C10	2	VIS/NIR Radiom.	4	Lamp 2
	AIRS-C10	3	VIS/NIR Radiom.	4	Lamp 3

Group 6: We have allocated all of Group 6 to the OBC Float test (AIRS-C5). This test involves letting the OBC cool and acquiring linearity data on the way down. This test requires the greatest temperature stability of the special tests and cannot be interrupted.

Group 7: In Group 7, we run the Channel Spectra Phase test, AIRS-C3. In this test, we deliberately perturb the optical bench temperature by ±1 K and acquire normal mode data. The gain is calculated at three temperatures (nominal, high, and low). Gain ratios provide valuable information regarding the phase of the channel spectra in the Spectral Response Functions (SRFs). This test also requires stability of the external AIRS environment. We have allowed the execution of AIRS-C10, which will cycle the lamps for one full orbit. This will not affect the performance of the IR bands; however, the wait time to restore normal periodic operation is more than 3 hours. We expect to be able to allow the full wait time while we transition the optical bench temperature.

3.3 Flagging Special Tests in the Mode Word

Data from special events must be flagged and routed appropriately. Since the procedures involve many different steps, or phases, we need to identify which part of the test we are in at any given time. This allows us to process the different parts appropriately as well as help us identify the state in which we have left the instrument in the unlikely event the procedure fails during the execution. Bits 0 though 2 of the AIRS mode word are used for the last phase (location within the special test procedure). Bits 3 through 6 are used to identify the overall special tests being performed. Bit 7 is the expedite flag. Data from the special tests are required whenever the expedite flag is on. Bits 8 through 11 are used to define the level of processing required by the PGS. Table 5 gives the requirements for labeling the mode word to identify the particular calibration test we are running, the phase within the test, and the level of processing.

3.4 Processing

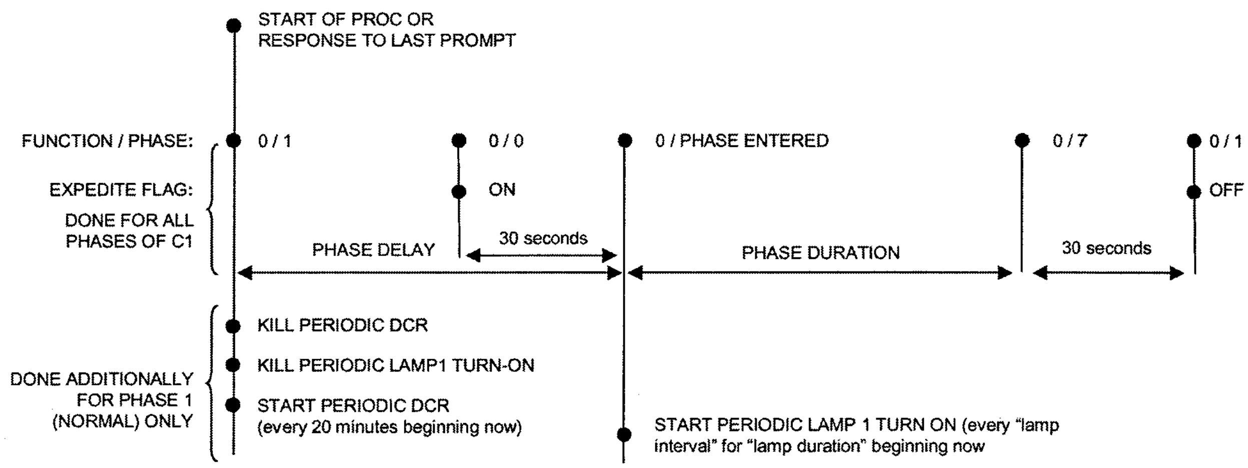
Processing of the special tests will follow algorithms presented in Reference 8, Special Calibration Test Processing Procedures. Reference 8 defines the algorithms for data reduction, the software to be used, and the expected results for each of the 12 special tests for calibration. Since the expected results are presented in detail in the referenced document, we will not present the expected results here in this calibration plan. Instead, we will focus on the objectives of the test and the procedural requirements.

3.5 Normal Mode Sensitivity Testing: AIRS-C1

We have reserved the first special test as a normal operational mode of the AIRS. We call this special calibration test AIRS-C1. This test has two parts. In the first part, called the "normal" phase in Table 5, the normal DCR and periodic Lamp 1 operations are reset and initiated. DCR is performed every 20 minutes. Lamp 1 is turned on for eight minutes every two orbits. This procedure must be run if the periodic DCR or lamp operations are terminated for any reason.

In the second part of this test, AIRS is operating in its normal data collection mode, but the data are flagged to identify special events, such as an external disturbance or a scene target of interest. A critical requirement of this test is that the data be expedited. Figure 5 shows the relationship between the phase identification (Table 5), the expedite ON and OFF command, and the sequence of events in the special test.

The operations team will run AIRS-C1 when there is a special disturbance for which we want to flag the data. For example, the disturbance can be vibrational, electromagnetic, electrical, or radiation. During this test, we are "listening" and assessing the impact to the AIRS noise performance. The test is a low sensitivity mode for measuring noise when compared to the Space View Noise Test. However, the instrument is maintained in its normal operation during this period.



USER ENTRIES:
1) PHASE (1, 2, 3, 4, 5, 6)
2) PHASE DELAY (31 to 12,000 seconds)
3) PHASE DURATION (8 to 3,600 seconds)
4) LAMP INTERVAL (30 TO 32,000 seconds)
5) LAMP DURATION (30 to 12,000 seconds)

SUBMODE: 0 × B (VIS to L2, IR to L2)

Figure 5. AIRS-C1 — Flagging and expedite requirements vs. instrument configuration.

Table 5. Special tests are identified through a high bit in the mode word as defined in this table.

Cal Function Name	Cal Func bits 3 - 6	Cal Phase (bits 0 - 2) 0	1	2	3	4	5	6	7	Submode bits 8 - 11	Proc. IR to	Proc. Vis to	Det. Gain	Description
AIRS-C1	**0**	Transition	Normal	Disturbance	Maneuver	Radiometric	Spectral	Spatial	Complete	11	L2	L2	Opt	Normal Operation, special events
AIRS-C2	**1**	Transition	Load A	A data	Load B	B Data	Load AB	AB Data	Complete	11	L2	L2	All	Guard Test
AIRS-C3	**2**	Transition	High Data	Low data	Nom Data				Complete	10	L1A	L2	Opt	Channel Spectra Phase Test
AIRS-C4	**3**	Transition	Pre Move	Post Move					Complete	10	L1A	L2	All	AMA Adjust
AIRS-C5	**4**	Transition	Normal	Cooldown	Warmup				Complete	11	L2	L2	Opt	OBC Float Test
AIRS-C6	**5**	Transition	Normal	Altered					Complete	10	L1A	L2	Opt	Variable Integration Time
AIRS-C7	**6**	Transition	Scanning	A Space	B Space	A/B Space	A OBC	B OBC	Complete	8	L1A	L1A	All	Space View/OBC Noise Test
AIRS-C8	**7**	Transition	Scanning	A Space	B Space	A/B Space	A OBC	B OBC	Complete	8	L1A	L1A	Opt	Radiation Circumvention Test
AIRS-C9	**8**	Transition	Nadir	Space	OBC/Pary	Parked			Complete	8	L1A	L1A	Opt	Scan Profile Test
AIRS-C10	**9**	Transition	VIS Lamp A	VIS Lamp B	VIS Lamp C	Off			Complete	11	L2	L2	Opt	VIS/NIR Operations
AIRS-C11	**10**	Transition	Scanner	Electronics	Cooler	PC	PV	TPattern	Complete	10	L1A	L2	Opt	Warm Functional Test
AIRS-C12	**11**	Transition	Scanner	Electronics	Cooler	PC	PV	TPattern	Complete	10	L1A	L2	Opt	Cold Functional Test
Reserved														
Reserved														
Reserved														
Reserved														

AIRS-C1 is also used to flag special calibration events. During the initiation and activation phase we will acquire complete orbits of normal data to evaluate the sensitivity to temperature fluctuations of the instrument or the orbital environment. Later, we will use this mode to capture data from special events, such as a deep space maneuver, or while viewing special Earth Scene targets. We will use a satellite orbit-tracking tool to identify times or orbits of interest. The relative time command will be used to acquire data during special parts of the orbit. The expedite feature of this test will facilitate the calibration team processing of the data to allow more rapid turnaround of the test success or failure to the operations team.

3.6 Guard Tests: AIRS-C2

The Guard test is used for assessing the radiometric and spectral stability of the AIRS instrument. This test is unique in that it runs the A, B, and A/B optimum gain tables that exercise the A, B, and linear combination of A and B sides of the detector arrays, respectively. This is particularly useful for characterizing the instrument noise or for balancing the signals from the projection of the entrance slit onto the detectors (as is done in AIRS-C4). Since we view the Parylene, we can also get a stability check on the spectral response.

The test exercises the A, B, or A/B optimum gain and circumvention tables and acquires 1 Granule (135 scans) of data in each case. The test requires the periodic DCR to be terminated, as we will be loading new gain tables and performing DCR within the procedure. Figure 6 shows the test timeline. The optics and detectors are cold; all systems are fully functional and stable. During these tests the AIRS instrument will be scanning the OBC blackbody and Parylene sources. No Earth Scene data are used; however, a good space view is required.

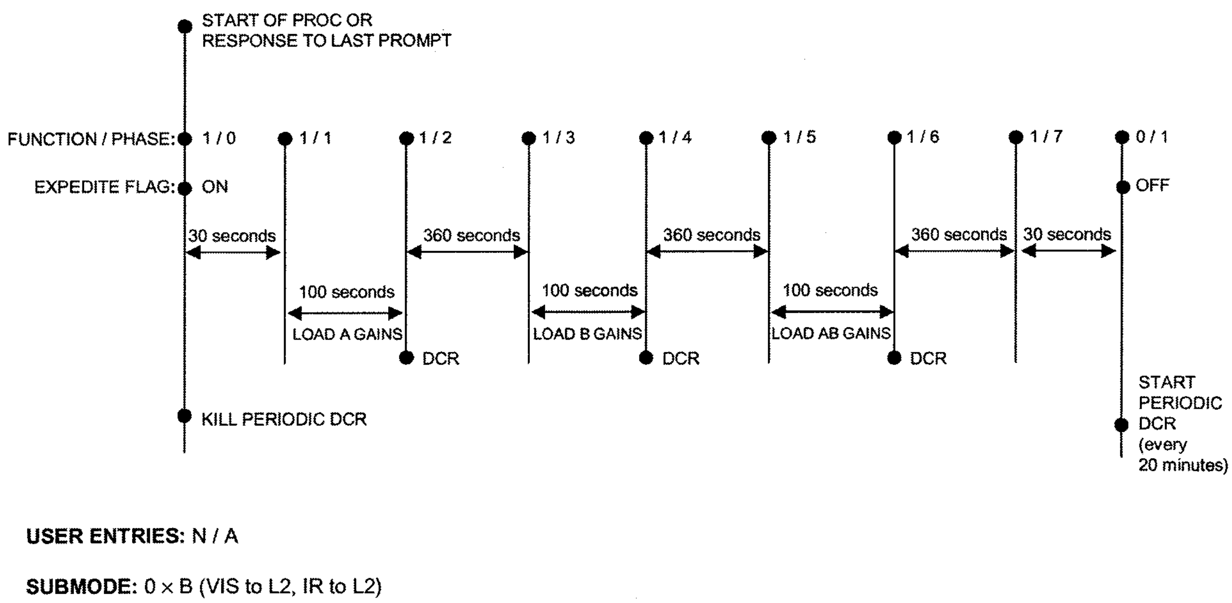


Figure 6. AIRS-C2 — Flagging and expedite requirements vs. instrument configuration.

The Guard test is to be run once every day in the first two weeks of checkout during the Activation and Evaluation (A&E) Phase.

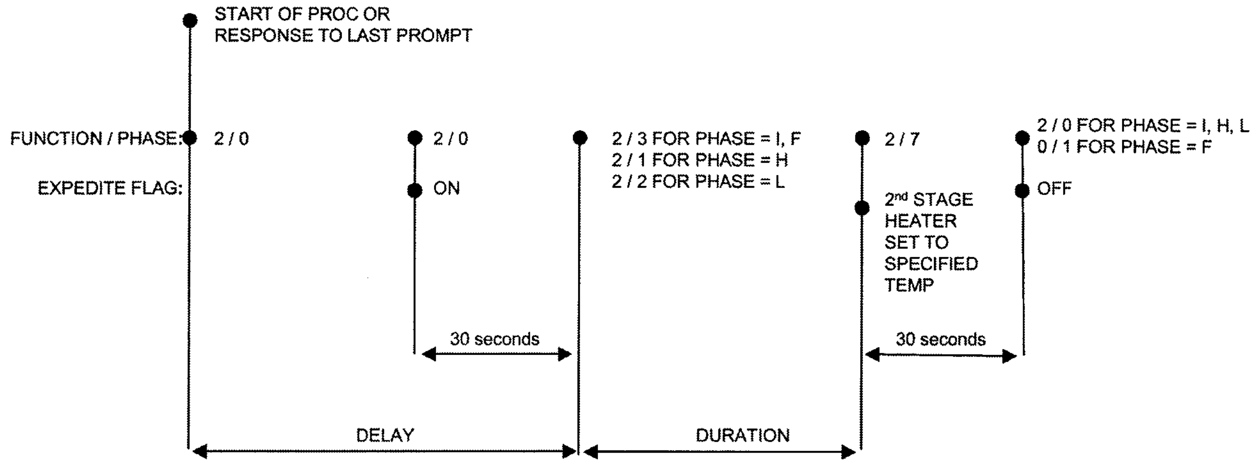
3.7 Channel Spectra Phase Test: AIRS-C3

The nominal AIRS spectral response functions are perturbed by a property of the entrance filters in the spectrometer. These entrance filters were placed perpendicular to the input beam and cause a small amount of frequency-dependent transmission modulation known as "channeling." The resulting channel spectra have been characterized pre-launch, but are subject to change of their phase in orbit as the temperature of the filters themselves change. The dependence of the phase on temperature has been well characterized pre-flight. A temperature sensor exists on the entrance filters that will be used to determine the phase during orbit.

AIRS-C3 will provide a verification of the phase using gains obtained from the OBC blackbody in orbit. This test involves acquiring data at one Kelvin above and below the nominal spectrometer temperature. This moves the channels (i.e., the phase of the channel spectra) in frequency relative to the nominal SRF positions. The ratio of the gains from the high to low temperatures versus frequency contains oscillations that can be used to deduce the phase of the channeling. This experiment has been demonstrated to successfully reproduce the channel spectra phase using data obtained at BAE SYSTEMS during pre-flight testing. This is discussed in more detail in Reference 8 and 10.

Figure 7 shows the flagging and expedite requirements for this test. As with most of these tests, we have allowed the test to commence after a specified delay from when the commands are entered. This allows us to run the test during any part of the orbit. We also set the expedite flag approximately 30 seconds before we acquire calibration data to help ensure that we don't lose scans near the edges of our data-collection window.

This test has four parts. First we acquire data without any change to the temperature; this phase is called "initial normal." This first phase also sets the temperature of the second stage radiator to 1 K above nominal after the data-acquisition phase. The temperature of AIRS spectrometer is monitored until it stabilizes at the desired temperature. The degree of stability is to be determined by the calibration team at the time of the tests. Once stable, the second phase of the test, "high data", is to be run. During this phase, we acquire data at the elevated temperature. Subsequently, we set the second stage radiator to the cold temperature 1 K below nominal. Again, once stabilized, we collect data at the low temperature and set the second stage radiator to the nominal level. Finally, at the nominal temperature, we acquire the "final normal" data set. The wait times between acquisitions is expected to be 8 to 16 hours. During this period we can run only limited tests, such as the VIS/NIR lamp tests, because the optical bench temperature of the instrument will be in transition. The FPA temperature and external environment (relates to BB source accuracy) must be well controlled and stable.



USER ENTRIES:
1) PHASE (I [initial], H [high], L [low], F [final])
2) CHOKE POINT HEATER TEMP SETTING (1010 TO 3610)
[EQUIVALENT to 165.004 °K - 143.858 °K for SIDE A and 166.421 °K - 145.002 °K for SIDE B]
3) DELAY (31 to 12,000 seconds)
4) DURATION (8 to 3,600 seconds)

SUBMODE: 0 x A (VIS to L2, IR to L1A)

Figure 7. AIRS-C3 — Flagging and expedite requirements vs instrument configuration.

3.8 AMA Adjust Test: AIRS-C4

The AIRS spectrometer alignment may degrade slightly during launch. For this reason, the instrument has a built-in capability to move the Adjustable Mirror Assembly (AMA) to affect realignment using commandable actuators.

The position of the AMA is characterized in terms of the position of the focus point with respect to the focal plane assembly, specified by the three non-orthogonal directions: the cross-dispersed direction ("x"), the along-dispersed direction ("y"), and the along-focus direction ("z"). This procedure determines the location of the focus spot in the "x", "y", and "z" directions and moves the mirror actuators to relocate the focus spot to the desired position. The top-level procedures, data processing, and operational considerations of this test are given below (see Reference 13 for a more detailed description).

3.8.1 Procedure Overview

The Guard test, AIRS-C2, is performed to acquire data on the A and B side detectors. The gains are calculated for each side and a displacement, Δx, is calculated at the FPA to "balance" the gains for each side. Note that detectors on the FPA do not balance at the same position. OBS (Paralyne) data are analyzed for translation, Δy, in the dispersion direction. The Δx and Δy values are placed in a spreadsheet and moves are converted to actuator motions. An AIRS operator enters the move parameters into the flight operations command procedure. This command procedure verifies the entry and makes the appropriate move. High-rate data are acquired during the entire move. After the move completion, AIRS-C2 is performed again. The data are again analyzed to determine the new A/B balance and spectral alignment. If the new position is adequate, no further moves are made; otherwise, the procedure is repeated.

3.8.2 Special Software

Adjustment of the AMA carries a risk of irretrievable loss of spectrometer alignment and, therefore, must be done with great care. In addition to the spreadsheet, the AIRS operations will incorporate a PC AMA calculator program for setting up and displaying the AIRS software commands for each of these moves. The program uses a log file that contains the current count and state of each of the three actuators (recorded after the last AMA move during ground testing). The calculator program also must be used to keep track of the actual moves by updating the log file. Please see Reference 8 for the algorithms and data-processing requirements for this test.

3.8.3 Operational Considerations

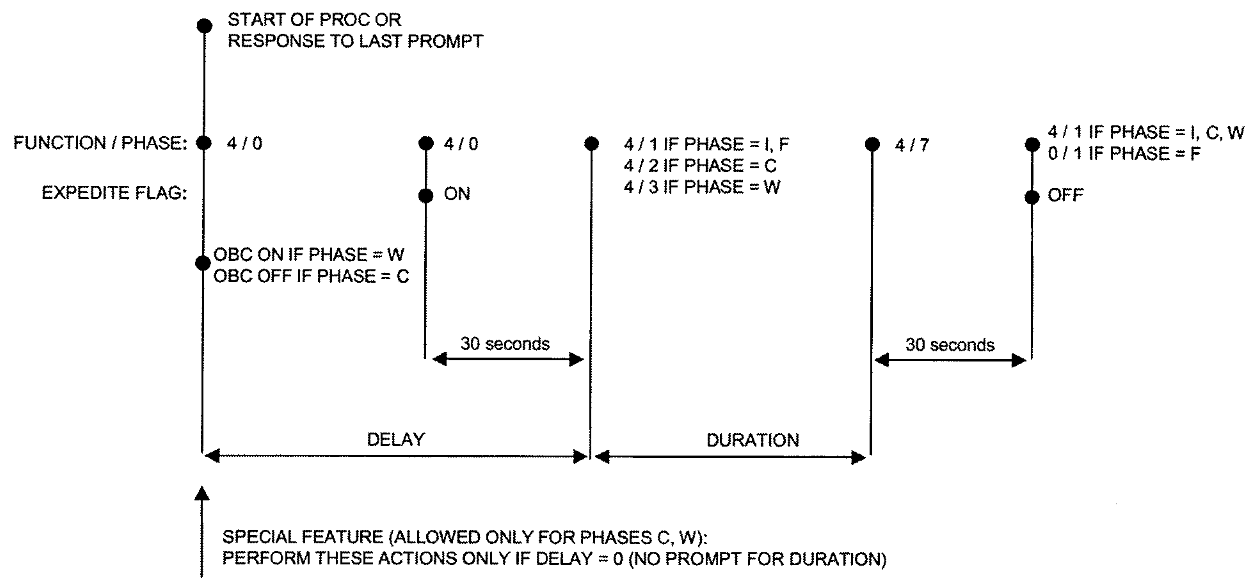
The AMA motion must be done in such a way that the final motion of each of the three actuators is a positive step of at least 50 counts. Usually, the motion is made in two sets of commands, the first with an overshoot of 50 counts in the negative direction for each actuator ("overshoot move") and the second with a return motion (positive) of 50 counts on each actuator. The flight software breaks down the commanded motions for each acuator into smaller steps, each of which is simulated and checked by the PC program against soft and hard limits. If the PC program simulation of the move reveals an out-of-limits condition during the move, the desired movement must be segregated by the operator into a number of sub-moves that in the aggregate achieve the desired movement while, at each step, do not violate limits.

It is very important to allow enough time between each commanded AMA step for the instrument response to be received and execution of the step to be verified by analysis of the telemetry. If the telemetry shows that a commanded move failed to reach the final position, the analyst must carefully determine how much of the move did take place. After making that determination, the analyst must hand edit the log file to reflect the actual movement that took place. Please see References 12, 13, and 14 for details regarding the AMA operation.

3.9 OBC Float Test: AIRS-C5

The OBC Float test involves turning off the temperature control heaters for the OBC blackbody (BB). This will cause the OBC to drop in temperature over the course of about 10-15 hours. At regular intervals during this timeframe we will observe the OBC BB temperature and radiometric data obtained from the sensor and assess performance indicators, including OBC blackbody stray light and AIRS instrument non-linearity. During the cool down, every attempt is to be made to acquire the data during the same portion of the orbit where the instrument environment is the same.

Figure 8 shows the schematic for the OBC float procedure. This procedure simply executes the flagging and expediting and delays data expediting until the desired time. Data are acquired prior to cool down, "I", during cool down, "C", during warm up, "W", and after stabilization, "F". The delays will be set to allow acquisition approximately every 1 degree from the nominal operating temperature of 308 K to the expected lowest BB temperature of 285 K.



USER ENTRIES:
1) PHASE (I [initial], C [cool down], W [warm up], F [final])
2) DELAY (31 to 12,000 seconds) (ALSO: 0 FOR PHASES C, W)
3) DURATION (8 to 3,600 seconds)

SUBMODE: 0 × B (VIS to L2, IR to L2)

Figure 8. AIRS-C5 — Schematic overview of the OBC Float Test.

3.10 Variable Integration Time Test: AIRS-C6

This test uses a feature of the AIRS instrument that varies the integration time of the detectors. When viewing a uniform target, this process allows us to determine the linearity of the signal-processing chain. The data will allow us to distinguish a change in detector non-linearity from a change in the electronics non-linearity.

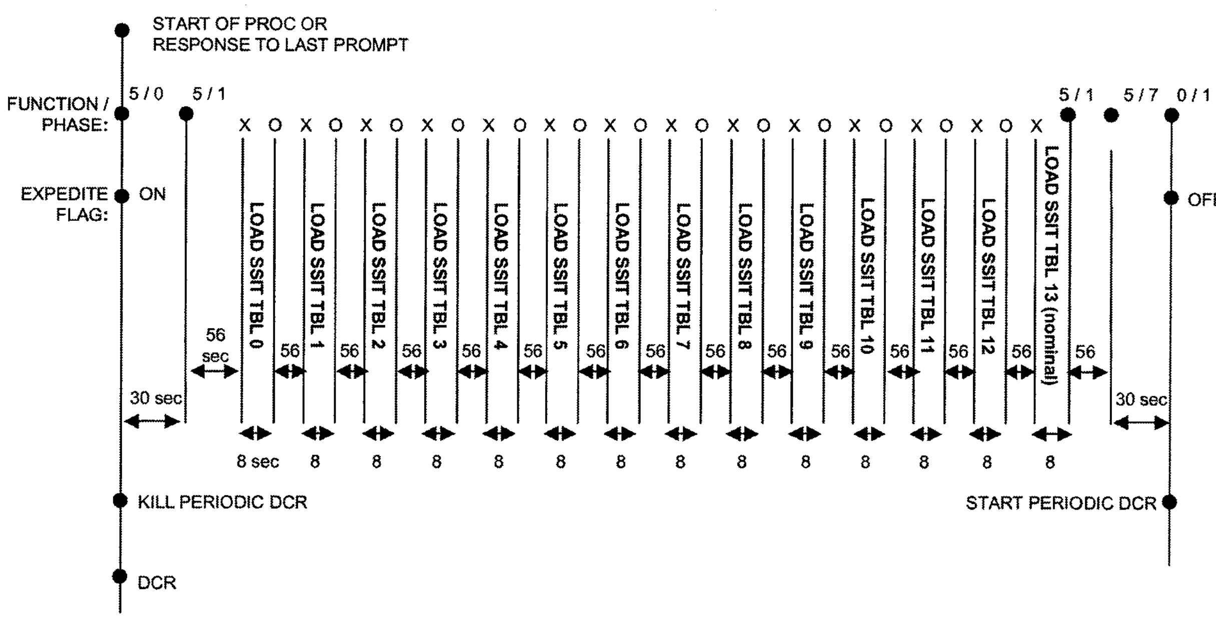
In this test we acquire 21 scans in the normal scan mode followed by 12 groups of 21 scans, each at successively lower integration times. Finally, we end with 21 scans at normal integration time. The integration times to be programmed into the command sequence are provided in Table 6.

Figure 9 shows the test schematic for the variable integration time test. It is similar to the others in its flagging and expediting approach.

Table 6. Integration Time Values to be Programmed during Variable Integration Time Test.

Integration Times Per Subframe (microseconds)

Module Step	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
0	2559.0	2559.0	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1092.4	1092.4
1	14900.0	8583.4	1308.5	1308.5	1308.5	1308.5	1308.5	1308.5	1308.5	1308.5	906.4	906.4
2	8745.5	5456.2	1272.5	1272.5	1296.5	1296.5	1302.5	1302.5	1302.5	1302.5	756.3	756.3
3	5114.0	3467.4	1242.5	1212.5	1284.5	1284.5	1296.5	1302.5	1302.5	1302.5	630.3	630.3
4	2643.1	2649.1	1212.5	1164.5	1278.5	1278.5	1290.5	1296.5	1296.5	1296.5	522.2	522.2
5	990.4	1194.5	1200.5	1116.4	1272.5	1272.5	1284.5	1296.5	1296.5	1296.5	438.2	438.2
6	372.1	540.2	1182.5	1068.4	1266.5	1266.5	1278.5	1290.5	1290.5	1296.5	360.1	360.1
7	264.1	378.2	1170.5	1020.4	1266.5	1260.5	1272.5	1290.5	1290.5	1290.5	300.1	300.1
8	204.1	360.1	1152.5	972.4	1260.5	1260.5	1272.5	1290.5	1290.5	1290.5	252.1	252.1
9	162.1	342.1	1140.5	864.3	1254.5	1254.5	1266.5	1284.5	1284.5	1290.5	204.1	204.1
10	150.1	168.1	1122.4	810.3	1248.5	1254.5	1266.5	1284.5	1284.5	1284.5	180.1	180.1
11	120.0	120.0	1092.4	780.3	1242.5	1248.5	1260.5	1278.5	1278.5	1284.5	150.1	150.1
12	120.0	120.0	1062.4	774.3	1236.5	1242.5	1260.5	1278.5	1278.5	1284.5	120.0	120.0
13	2559.0	2559.0	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1092.4	1092.4
Nominal	2559.0	2559.0	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1296.5	1092.4	1092.4



USER ENTRIES: N/A

X = Function/Phase 5 / 0
O = Function/Phase 5 / 2

SUBMODE: 0 × A (VIS to L2, IR to LIA)

Figure 9. AIRS C6 — Space View/OBC Noise Test schematic. The test is run for each set of gain and viewing requirements.

3.11 Space View/OBC Noise Test: AIRS-C7

In this test, the scan mirror is stopped with AIRS viewing through the space viewport at 90 degrees. The test is also designed to allow static viewing of the OBC. With the scan mirror stopped, we can extend the noise characterization frequency range from its current 0.4 Hz to approximately 47 Hz. The plan is to acquire data to evaluate the instrument noise, radiation effects, and “popping”. The independent variables will be orbital, instrument, and celestial environmental parameters.

Figure 10 shows the test sequence. There are specific combinations of gains and views that are required. First, we must acquire space view data for the A, B and A/B Optimum gains. This data will be used for assessing the Gaussian nature of the noise and for looking at “pops”. A pop is defined as a stepwise change in the instrument offset between successive groups of 4 space views. For most detectors, this is a very infrequent event. The results of the noise analysis will assist in selection of a new A/B Optimum gain set. The baseline pre-flight characteristics will be correlated with in-orbit measurements. Because the noise characteristically may change with each FPA cool down, this test should be preformed after each cool down.

The test is also configured to stare at the OBC blackbody. This will be done during the radiation circumvention test. The photon noise is higher in the OBC blackbody sector and will affect the circumvention threshold selection.

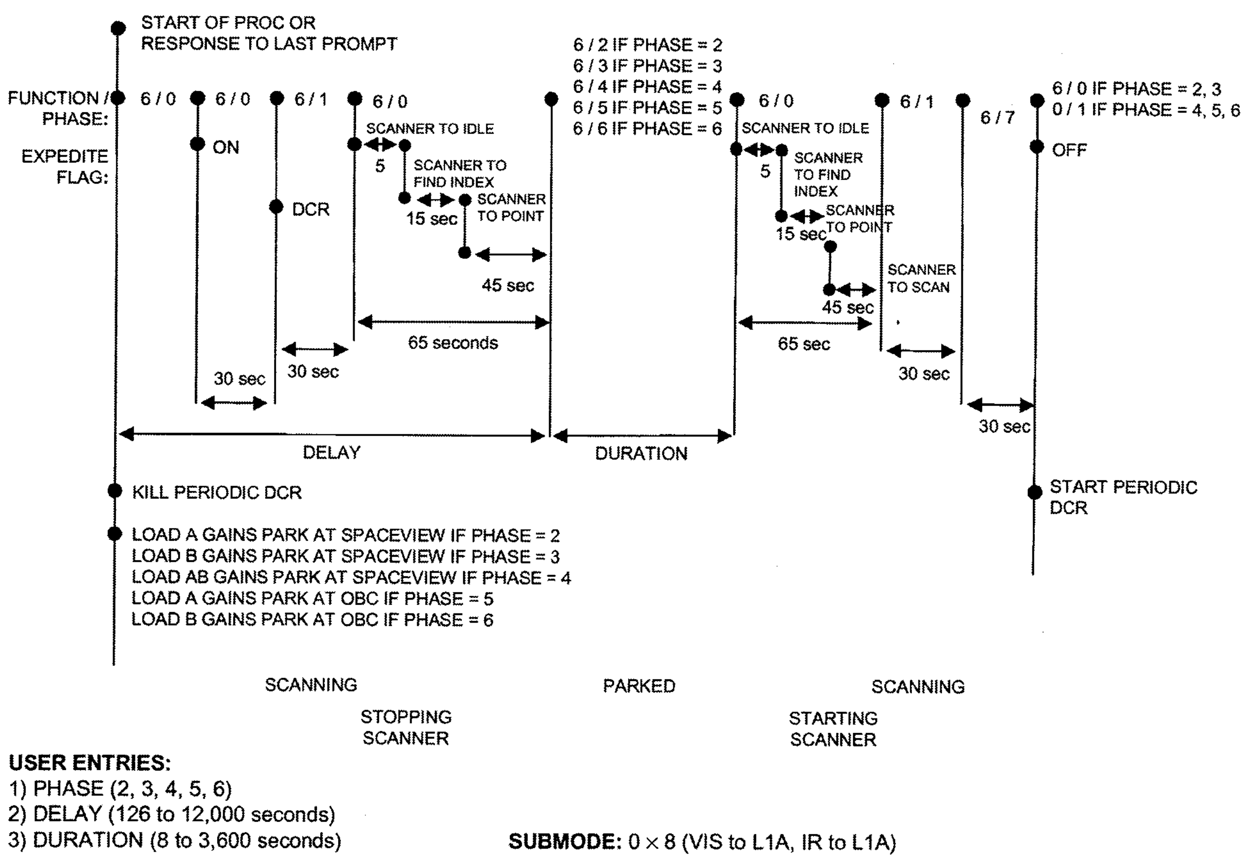


Figure 10. AIRS C7 — Test sequence for the Space View Noise Test.

3.12 Radiation Circumvention Test: AIRS-C8

Proton and Bremstralung events in the photovoltaic (PV) detectors cause fast signal spikes, which the AIRS electronics can detect and remove from the signals. The process to detect the events is to take the second difference for each PV detector of the digitized subsample signals (prior to forming A/B gain weighting and the summed footprints) and threshold the result. The threshold is adjustable for each detector. If a threshold is exceeded for any subsample, that subsample is replaced by the mean of the immediately preceding and following subsamples. A counter tallies all threshold crossings for all detectors for the 96 active footprints into a single count for the scan cycle.

Unique thresholds are established for all detectors through a table of Circumvention Levels (one value per detector) and a Circumvention Base Threshold (one value that multiplies all the values in the Circumvention Level Table). The range of Circumvention Levels, DN_{LEVEL}, is 1/128 to 1, in 15 quasi-logarithmic steps, and OFF. The range of the Circumvention Base Threshold, DN_{BASE}, is 1 to 32767 and OFF. For a given detector, the threshold is the product of the base threshold and the level and is compared with the second difference signal, in counts.

$$DN_{TH} = DN_{BASE} \times DN_{LEVEL}$$

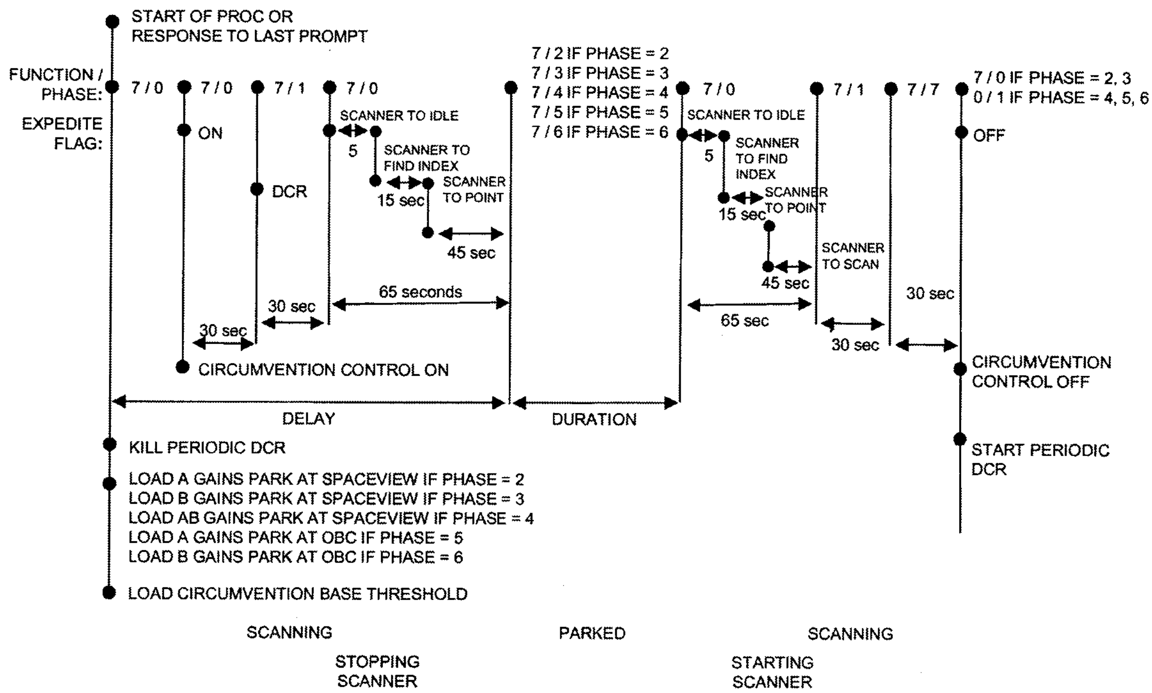
This test evaluates the effectiveness of the Circumvention Level table for various Base Threshold settings and the orbital environment. The test is constructed to obtain noise behavior versus orbital position with circumvention processing "off"; that is, by running AIRS-C7. The noise data is analyzed using median statistics to identify radiation events. The threshold values are calculated with this data and loaded into AIRS. The effectiveness of the new levels are determined by repeating the test with the Circumvention processing "on", as performed in AIRS-C8. The test is identical to AIRS-C7 except in the table loading and turning on of Circumvention processing. See Figure 11.

3.13 Scan Profile Test: AIRS-C9

The AIRS scan mirror rotates 360 degrees, but not at a constant velocity. The scan mirror slows before reaching the Earth view region (± 50 degrees) and speeds up afterwards. By rotating the slow period of the scan (the Earth Sector) to be centered on the calibration targets, we can get additional information regarding the radiometric calibration. This procedure rotates the scan profile then acquires data on the calibration targets.

The test can be performed with alternate gain tables; however, the information desired is of the spatial type and should not be particularly different for A or B side gains. For this reason, A/B optimum gains should be loaded for the first time we run this test. The sections that follow describe the types of observations to be made from the acquired data sets.

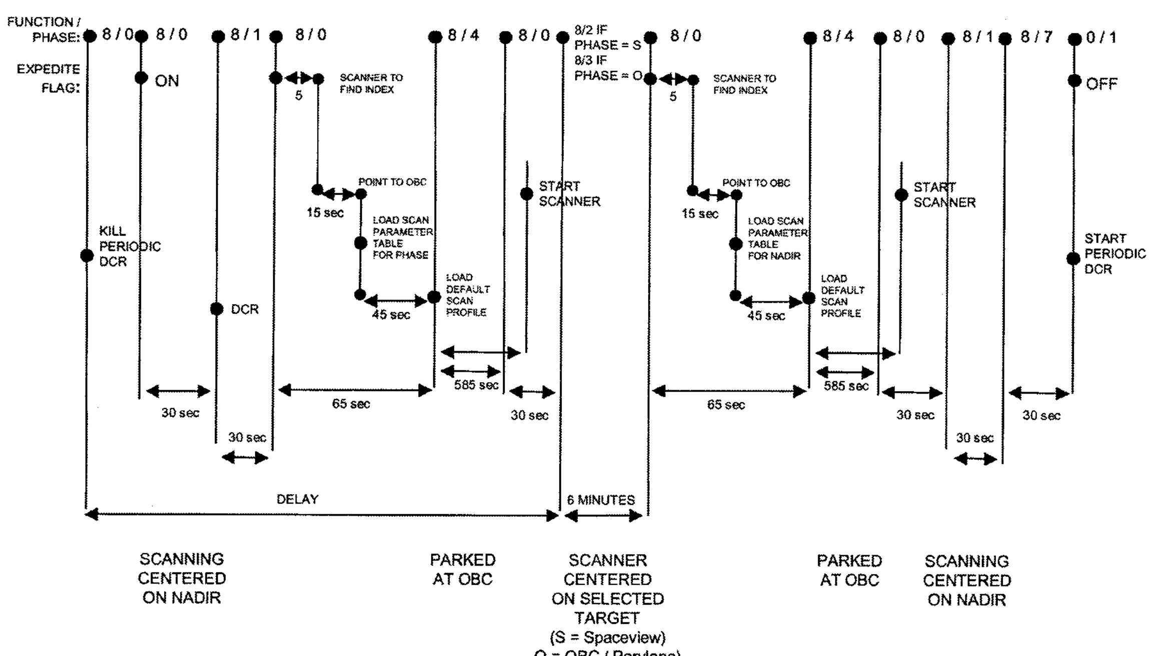
Figure 12 shows schematically the command sequences required to execute the Scan Profile test. We must first stop the scan mirror and load the new profile prior to running the rotated scan profile. The mirror must again be stopped and the nominal profile loaded prior to completion of the test.



USER ENTRIES:
1) PHASE (2, 3, 4, 5, 6)
2) DELAY (126 to 12,000 seconds)
3) DURATION (8 to 3,600 seconds)
4) CIRCUMVENTION BASE THRESHOLD (0 to 4035)

SUBMODE: 0 × 8 (VIS to L1A, IR to L1A)

Figure 11. AIRS-C8 — Test sequence is identical to AIRS-C7 except for table loads and turning on of circumvention processing.



USER ENTRIES:
1) PHASE (S [space], O [OBC])
2) DELAY (741 to 12,000 seconds)

SUBMODE: 0 × 8 (VIS to LIA, IR to LIA)

Figure 12. AIRS C9 — Test sequence for the Scan Profile test.

3.13.1 OBC Blackbody/Parylene Alignment and Stray Light

With a single offset of the scan profile, AIRS can get a view of the Parylene, the OBC blackbody, and the photometric calibration with the slow part of the scan. This is shown schematically in Figure 13. The nadir angle is rotated to 214 degrees (nadir being zero). The Parylene data collection footprint now appears at approximately 95 degrees, providing a good space view. Data obtained with the slow part of the scan produces many footprints (rather than 1 during the normal scan) of each calibration. We plan to use this data to assess the uniformity of the OBC blackbody and registration in the normal scan profile. This then verifies the fidelity of the single sample used during normal operation. Of major concern is the radiance contribution from the region surrounding the blackbody. It is believed that this could be a potential source of stray light and, therefore, must be adequately characterized. We would like to perform this test under various Earth-environmental conditions in case the upwelling radiance produces a contribution to the observed blackbody radiance.

With the same scan profile, we get many footprints to view both the Paralyne and phometric calibrator targets; therefore, we can determine whether they are aligned properly and assess their spatial uniformity. Although this will most likely be done very infrequently, it will occur at least once after launch to check for shifts due to vibration.

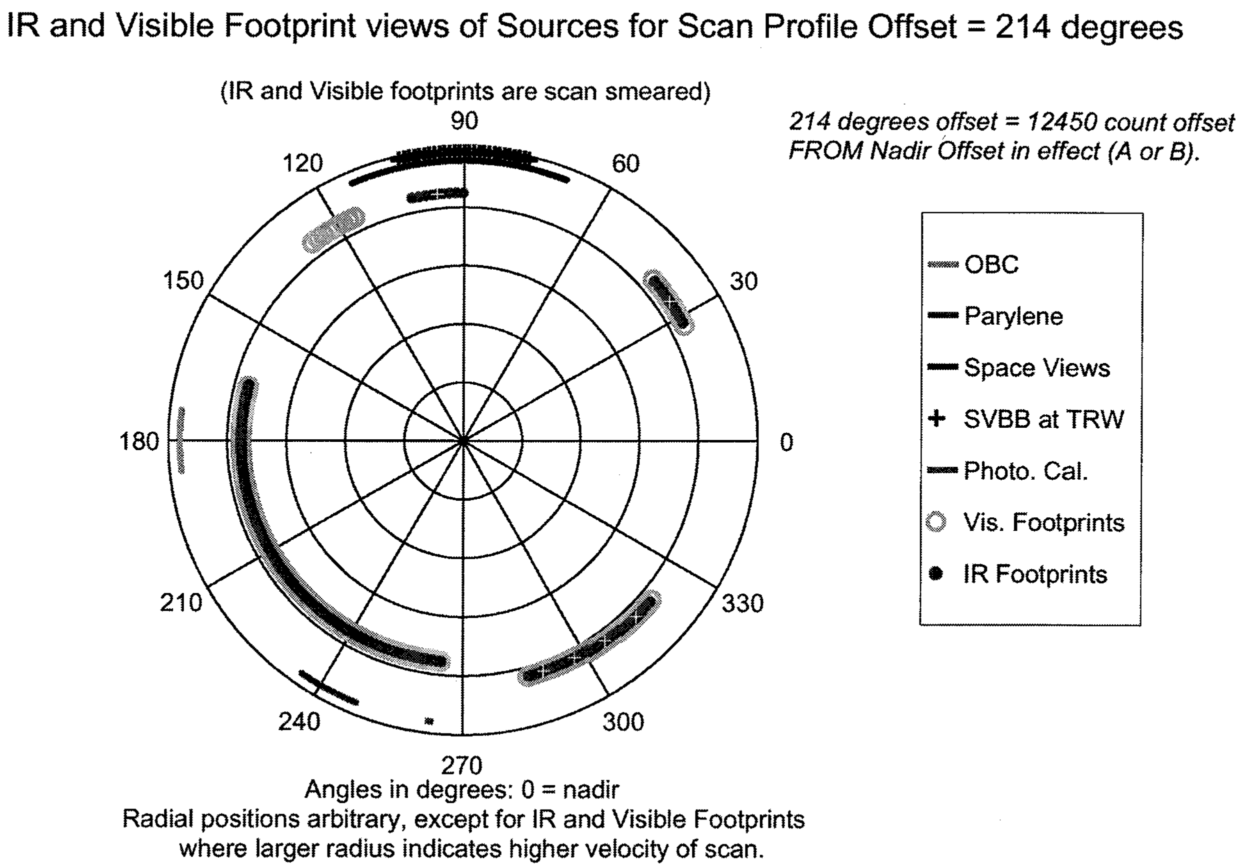


Figure 13. Rotated Scan Profile obtains slow scan views of OBC blackbody (180°) and Parylene (242°).

3.13.2 Space View Stray Light

It has been stated above and in the Level 1B ATBD that one or more of the four space view samples could potentially be contaminated with stray light. By rotating the Earth sector to be centered on the space viewport, we get many samples that can be used for characterizing the space viewport background radiation. As can be seen in Figure 14, the scan angle ranges from 30 degrees to approximately 130 degrees, passing through the Earth limb (at approximately 65 degrees) and the space view (at approximately 90 degrees). This allows us to fully trace the limb profile. There may also be calibration and scientific implications of scanning through the limb that have not been fully realized at this time. Additionally, we can characterize the effects of the moon in the space viewport on calibration.

3.14 VIS/NIR Radiometric Test: AIRS-C10

The VIS/NIR Radiometric test provides information regarding the VIS/NIR detector response. For more information on the type of information obtained from this test, please see the *AIRS Level 1B Algorithm Theoretical Basis Document (ATBD) Part 2 (VIS/NIR)* (Reference 3). The test is primarily dedicated to the assessment of the radiometric gain stability of the VIS/NIR channels as a function of orbital and environmental parameters.

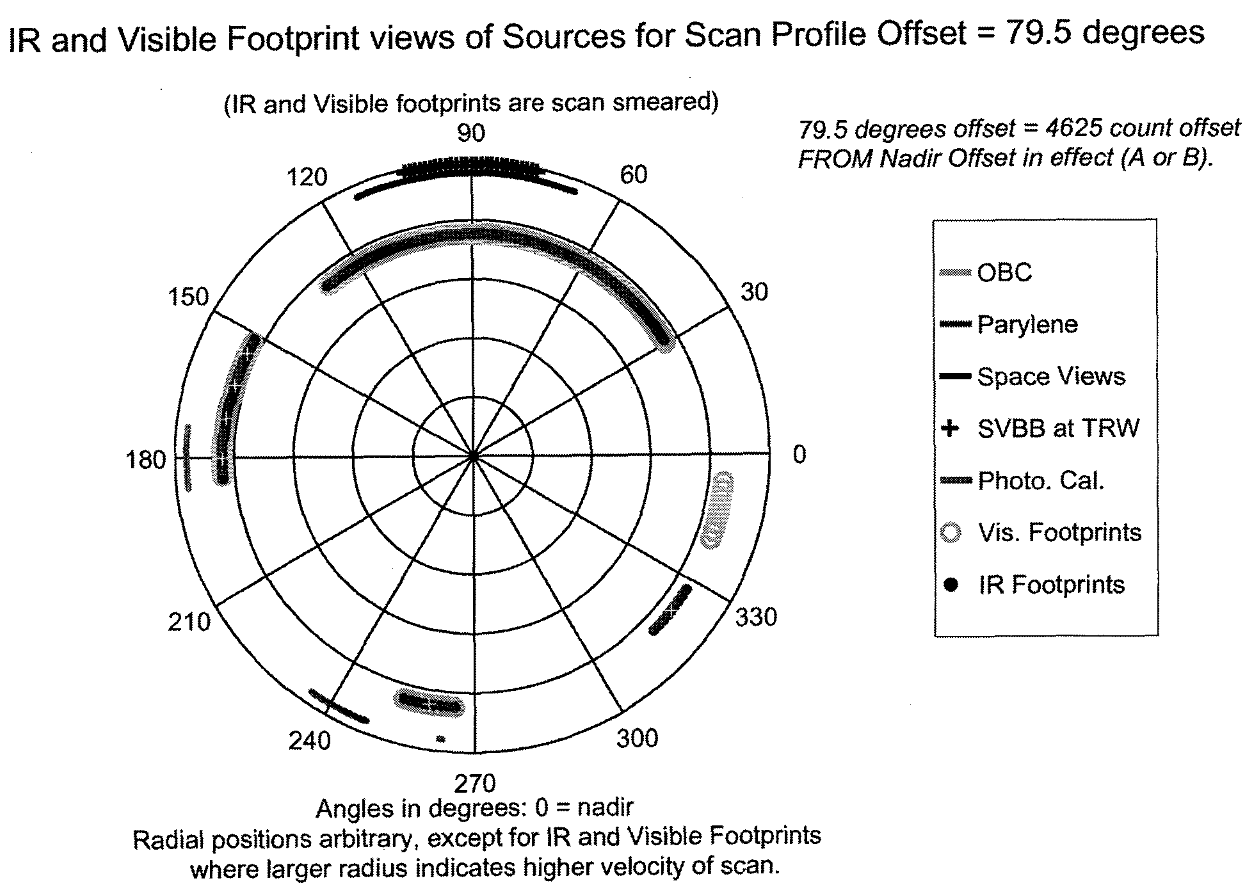
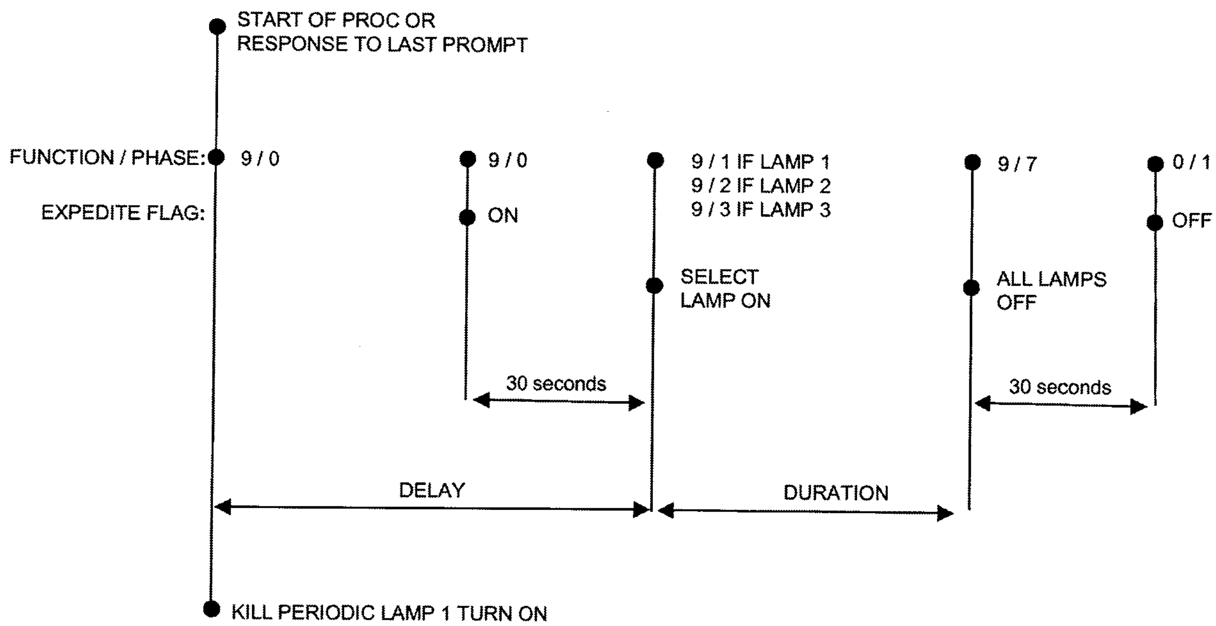


Figure 14. A second profile obtains slow scan views of the space viewport (90°) and the Earth horizon.

A single procedure runs any of the 3 lamps for a specified duration. Figure 15 shows the schematic representation of the test sequence. The sequence is similar to the other calibration procedures and includes a delay to the desired lamp turn on time from when the commands are set. This allows us to run the lamps wherever desired in the orbit.

During normal calibration sequences (see reference 3 for details), each lamp is turned on for 8 minutes. Lamp A (an arbitrary designation) is used every 180 minutes (approximately 2 orbits). Note that the intent is to not be exactly commensurate with the orbital period; therefore, over time, calibrations will occur at all orbital positions. Lamp B will be used once every 300 hours (~200 orbits); Lamp C every 750 hours (~500 orbits). This approach is designed to maximize bulb life while maintaining an unbroken calibration chain.

In addition to these normal calibrations, early in the mission, each lamp will be turned on for one complete orbit, thereby establishing a baseline to reveal any effects due to orbital position, Sun geometry, etc. This test may be carried out periodically as needed to diagnose the system.



USER ENTRIES:
1) DELAY (31 to 12,000 seconds)
2) DURATION (30 TO 12,000 seconds)

SUBMODE: 0 × B (VIS to L2, IR to L2)

Figure 15. AIRS-C10: Test Sequence for VIS/NIR Lamp Special Calibrations.

3.15 Warm Functional Tests: AIRS-C11

3.15.1 Science Data Test Pattern

With the instrument configured for science data acquisition, a mode is commanded which inserts a fixed pattern of digital data into a point equivalent to the A/D converter outputs in the instrument electronics signal chain. Examination of the received data therefore verifies the on-board signal processing as well as the data links through the spacecraft and to ground sites. The test should be run on both redundant sides of the electronics. However, because of the length of time needed to change redundant sides, the test should be run for the current operating side and run separately only when the instrument has been configured to the other side for other reasons. The commands and data loads to the instrument to enter the mode are:

Enable Circumvention Control: SWL = 0 (enable), CV = 0 (enable)

Load Circumvention Base Threshold: threshold = 3000 (decimal)

Load Gain and Circumvention Level tables (defined specifically for this test)

Subsample weights for all subsamples 1 to 16 set to 1

Shift Factor for M1 & M2 set to 1

Shift Factor for M3 to M10 and PC detectors set to 0

PC detector offset set to 3888

Set Test Mode Master Toggle to enable (E = 1)

Select Test Pattern Packet to normal (Test Mode = 0)

Set Test Pattern Advance Interval to subsample (FP = 0) and On / Off Toggle to enable (T = 1)

Data should be collected for one or more minutes. Please refer to Reference 8 for data processing procedures. The routine examines the AIRS telemetry to verify proper setup of the instrument and then compares the output of every IR spectral sample for every footprint and scan to a table of expected values. Where values depart from expected, the scan, footprint and spectral sample numbers (or a range) are reported.

3.15.2 Warm Focal Plane Responses

When the IR focal planes are near ambient temperatures, they have no significant IR response. However, the read out circuitry can indicate on scale signals and noise levels if the detector integration times are suitably shortened. Transients associated with turning on the power to detector modules and performing the DC restore operation (for modules 3 to 10) can be used to indicate signal path integrity from the modules to the sensor electronics and to the output of AIRS. The test is executed first observing the A-side detector outputs (of the PV modules) and a second time observing the B-side outputs. For this test the following steps are followed:

1. Load Gain table for A-side gain = 2 and B-side gain = 0 (only the A-side signals are thereby observed).
2. Set up the focal plane modules for normal operation with A-bias generators EXCEPT for integration times shortened to 48 microseconds for modules 1 and 2 and to 18 microseconds for modules 3 to 10.
3. Remove power to all focal plane modules and bias to the PC detectors.

4. Send a delayed command to ENABLE PC and PV Detector Overtemperature Shutdown 5 minutes after the current time.
5. Send a command to DISABLE PC and PV Detector Overtemperature Shutdown.
6. Command A-side Power ON to all PV modules and A-side Bias generator ON to the PC detectors (note the power to modules 5 to 10 must be cycled 5 to 6 times to ensure proper activation of these modules).
7. Wait ~30 seconds to observe detector signals.
8. Command a DC restore to modules 3 to 10.
9. Wait ~30 seconds to observe detector signals.
10. Command Power OFF to all PV modules and Bias OFF to the PC detectors.
11. Send a command to ENABLE PC and PV Detector Overtemperature Shutdown.
12. Wait ~30 seconds to observe detector signals.
13. Load Gain table for A-side gain = 0 and B-side gain = 2 (only the B-side signals are thereby observed).
14. Set up the focal plane modules for normal operation with B-bias generators EXCEPT for integration times shortened to 48 microseconds for modules 1 and 2 and to 18 microseconds for modules 3 to 10.
15. Remove power to all focal plane modules and bias to the PC detectors.
16. Send a delayed command to ENABLE PC and PV Detector Overtemperature Shutdown 5 minutes after the current time.
17. Send a command to DISABLE PC and PV Detector Overtemperature Shutdown.
18. Command B-side Power ON to all PV modules and B-side Bias generator ON to the PC detectors (note the power to modules 5 to 10 must be cycled 5 to 6 times to ensure proper activation of these modules).
19. Wait ~30 seconds to observe detector signals.
20. Command a DC restore to modules 3 to 10.
21. Wait ~30 seconds to observe detector signals.
22. Command Power OFF to all PV modules and Bias OFF to the PC detectors.
23. Send a command to ENABLE PC and PV Detector Overtemperature Shutdown.
24. Wait ~30 seconds to observe detector signals.

To analyze the collected data, observe the time sequential outputs of selected detectors from each module. The data-reduction routines provide plots of the response of three detectors from each of the 17 AIRS arrays in 17 figures. The time histories should be observed for module turn on (signal level shifts of ± several thousand counts, depending on the module), the level shift associated with the DC restore operations in modules 3 to 10, and module turn off. The PC detectors should show a decaying transient after bias turn on, since they are AC coupled to their pre-amplifiers. At high signal resolution, an increase in noise should be noted from before to after power on for all detectors.

3.16 Cold Functional Tests: AIRS-C12

This test observes detector outputs when the focal plane is at or near operating temperature (~65 K or below, for this test). Transients associated with turning on the power to detector modules and performing the DC restore operation (for modules 3 to 10) are used to indicate signal path integrity from the modules to the sensor electronics and to the output to AIRS. The test is executed first observing the A-side detector outputs (of the PV modules) and a second time observing the B-side outputs. For this test the following steps are followed:

1. Load Gain table for A-side gain = 2 and B-side gain = 0 (only the A-side signals are thereby observed).
2. Set up the focal plane modules for normal operation with A-bias generators and normal integration times.
3. Remove power to all focal plane modules and bias to the PC detectors.
4. Command A-side Power ON to all PV modules and A-side Bias generator ON to the PC detectors (note the power to modules 5 to 10 must be cycled 5 to 6 times to ensure proper activation of these modules).
5. Wait ~30 seconds to observe detector signals.
6. Command a DC restore to modules 3 to 10.
7. Wait ~30 seconds to observe detector signals.
8. Command Power OFF to all PV modules and Bias OFF to the PC detectors.
9. Wait ~30 seconds to observe detector signals.
10. Load Gain table for A-side gain = 0 and B-side gain = 2 (only the B-side signals are thereby observed).
11. Set up the focal plane modules for normal operation with B-bias generators and normal integration times.
12. Remove power to all focal plane modules and bias to the PC detectors.
13. Command B-side Power ON to all PV modules and B-side Bias generator ON to the PC detectors (note the power to modules 5 to 10 must be cycled 5 to 6 times to ensure proper activation of these modules).
14. Wait ~30 seconds to observe detector signals.
15. Command a DC restore to modules 3 to 10.
16. Wait ~30 seconds to observe detector signals.
17. Command Power OFF to all PV modules and Bias OFF to the PC detectors.
18. Wait ~30 seconds to observe detector signals.

The data are analyzed as done in the Warm FRA test discussed in the previous sections. Future versions of this test are expected to exercise cross-strapping configurations.

4 Post Processing of L1B Quality Assessment (QA) Data

The Level 1A and Level 1B Quality Assessment (QA) data provides the necessary indicators to evaluate instrument health status and calibration. The requirements defined herein will lead to a system to present summary reports and to perform long-term trending of the QA indicators and telemetry on a regular basis. The AIRS L1B QA Plan presented here is in accordance with the overall AIRS QA Plan (Reference 16)

We will not discuss here the detailed requirements of the Level 1A processing except to say that all the relevant telemetry from the instrument shall be converted to engineering units and presented in the Level 1A data. Programs will be developed to evaluate the engineering telemetry for health, safety, status, performance, and trends. This is discussed in Section 5.

The Level 1B Quality Assessment (QA) products contain a subset of the Level 1B Radiance products, including sufficient indicators and telemetry to allow assessment and monitoring of the instrument calibration performance without requiring the injestion of the entire L1B Radiance product. The following sections provide the plans for post-processing the QA indicators into metrics. These metrics will be monitored, allowing the assessment of instrument and algorithm performance, both instantaneously and as functions of time and instrument environment. The plan is comprised of objectives presented at the beginning of each subsection followed by specified requirements for post processing the L1B QA indicators. A complete discussion of the algorithmic and specific QA indicators required is provided in Reference 6.

4.1 Generation of Daily Quality Assessment and Telemetry Products: Level 1C

The Level 1B software produces statistics for the key quality assessment data and all engineering telemetry. The statistics are provided once per granule and cover a wide range of parameters, including gains, offsets, spectral centroids, and all engineering telemetry. Figure 16 shows the plan.

The Product Generation Executable (PGE) is required to post-process the Level 1B and generate a Level 1C data product for the QA data and the engineering telemetry. The Level 1C data product summarizes one day of data. This summary uses the standard Level 1B-type engineering structures (for example, max, min, mean, standard deviation, etc.) covering the whole day of data. This PGE only needs to be run at JPL because only the AIRS calibration team requires the data for monitoring of the instrument performance, health, and safety. The output files have a very similar data structure or format as the Level 1B but cover timeframes of one day, rather than one granule.

The Level 1C only puts out one set of statistics per QA indicator or telemetry value (sometimes one set per channel) over the whole day. These are useful for a daily summary. However, we may want all the values in a day (that is, for all granules). For this, we would have to go back to the Level 1B files. We plan to write special code that would read in the L1B files and aggregate them into a daily diary of the parameters. We may only extract the mean values, for example. This software would not be part of the PGE as we do not envision needing daily diaries of QA or telemetry parameters for every day.

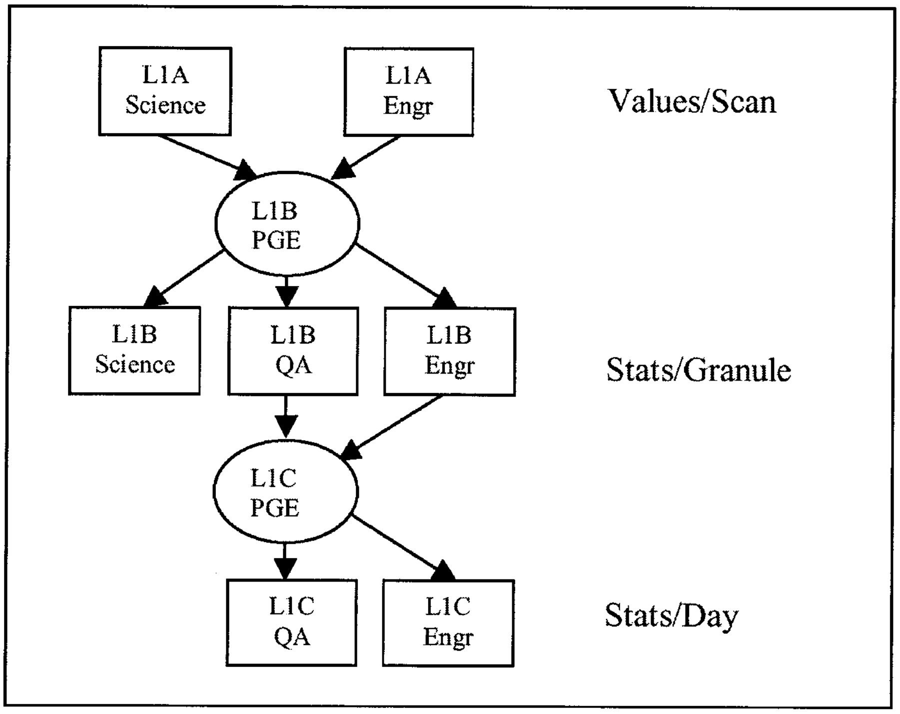


Figure 16. Plan for generation of Daily QA and Telemetry Files (L1C).

4.2 Radiometric Calibration Metrics

The objective of the on-board radiometric calibration is to convert the digital numbers obtained from AIRS into radiances that can be traced to known pre-flight calibration standards. Please refer to the AIRS Level 1B ATBD (Reference 2) and the *AIRS L1B IR Algorithm and QA Processing Requirements* (Reference 6) for a description of the radiometric calibration algorithm and QA Indicators. The only radiometric source contained within the AIRS instrument is the On Board Calibrator (OBC) blackbody. This device is described in detail in the AIRS instrument calibration plan (Reference 1). Views of this target combined with the space view provide a continual update of the instrument gain and offset. Trending many of the radiometric L1B QA Indicators and developing metrics will help us identify contaminants and obtain estimates of the instrument radiometric sensitivity.

4.2.1 Space View Offset and DC Restore

One major concern described in the Level 1B ATBD is the non-uniformity of the four space-view measurements obtained on each scan line. Several concerns exists with the space view look:

1. Space view samples closest to the Earth limb may experience higher signal counts than the others, thus indicating stray Earthshine. The dependent variable will be the relative space view offsets; the independent variable will be the orbital and celestial parameters.
2. Space view samples closest to the spacecraft side may experience stray light from Earth glint off of blankets or other heretofore-unknown possibilities. The same dependent and independent variables will be tracked.

3. We will also monitor the space view statistics versus orbital, celestial, and Earth Scene environmental parameters. Any large variations between samples will indicate possible stray sources, such as the moon, or excessive noise spikes.
4. Space view noise will be closely monitored and may depend on the temperature and radiation environment.

DC restore (DCR) is the process wherein electronic drift is compensated. Infrared detectors are expected to drift; however, excessive drift could lead to low- or high-end saturation of signals. There are several reasons why we need to track the DCR process:

1. Excessive drift may indicate a problem with the temperature control of the FPAs or other electrical problems. The dependent parameter will be the space view difference between scans; the independent parameter will be celestial, orbital, and instrument parameters.
2. The DCR may not be working properly and cause premature saturation or clipping of the signals. For this reason, we look at the space view and OBC counts and verify they are within limits as required by the DCR process.

4.2.1.1 QA indicators Post-Processing

Science Counts Limit Detection: Report in file format the number of science raw data numbers out of limits, input_sci_counts(Num_hi, Num_lo), any time it is not zero for any channel and the Calibration Status Word has determined L1B to be valid. Send an automated message to the AIRS Calibration Team that an out-of-bounds condition has taken place and requires immediate attention. Messages should be sent in groups of 3 hours worth of granules.

Space Counts Limit Detection: Report in file format the number of science raw data numbers out of limits, input_space_counts(Num_hi, Num_lo), any time it is not zero for any valid channel and the Calibration Status Word has determined L1B to be valid.

Drift Analysis: Generate images of the mean space view offset dn (offset_stats mean) normalized to the mean for the first granule following the first DCR in the day versus channel and granule. For a single day, we should have 240 granules; the image will be N_chan x 240 pixels, where N_chan is the number of valid channels in each of the 17 modules. There will be a total of 17 plots. These plots will be 9 on one page and 8 on the next. The plots shall be false color coded with a color bar. We should see the DC-restore process working on all the channels and the levels staying within the limits set by the limit_high,low_sv.

Space View Uniformity Amongst 4 Views: Plot the spaceview_selection bit 4 for all scans and all granules within the day. Identify granules where the moon is in the space viewport and remove from the granule averaging of the next plot of the difference between space views. Correlate conditions where delta_moon is violated with the presence of the moon in the space viewport.

Plot the difference between the first space view, input_space_counts(mean,1) and the remaining space views, input_space_counts(mean, 2, 3, and 4), for each channel averaged over all granules in the day (without the moon in the port). Plot the difference versus channel. There will be 3 plots: one for each space view. We should see the differences be zero on the average. If not, we have a systematic offset error of one of the space views.

Space View Uniformity vs Orbit: Plot the difference between the first space view input_space_counts(mean,1) and the remaining space views, input_space_counts(mean,2, 3, and 4), for the average of all channels within each of the 17 modules versus granule in the day. There will be 17 plots on three charts. Analyze the data for harmonic behavior, such as an orbital thermal or day/night dependence.

Non-Gaussian Noise Detection (Pops or 4-sigma events): Plot the number of outliers in space view differences, input_space_diff(Num_hi) + input_space_diff(Num_lo), for each space view summed over one day versus valid channel (omit granules with the moon in the space view). We expect this number to be less than or equal to 8 for a noise limit detection threshold of four sigma. Plot the location of the max values.

On a companion chart, plot the sum of outliers versus latitude and longitude of each granule on an Earth projection. Plot each channel within the image in a 50×50 square grid located at the granule start. This will make an image roughly $\sqrt{240} \times 50 = 775$ pixels square. Alternately plot channel versus granule versus number of outliers.

4.2.2 Radiometric Offset, ao (Polarization Correction)

Polarization correction is the process wherein a small radiometric correction is applied to the data to correct for the scan-angle-dependent polarimetric effects. We would like to track this process for several reasons:

1. Excessive correction amplitudes could indicate possible algorithm implementation concerns.
2. We must look at the corrected radiances in the L1B data versus scan angle and see if there are biases. This will require averaging over many granules to smooth out the presumably random upwelling radiances. Please note that we must look at corrected radiances in the Level 1B science data product to track scan angle dependencies.
3. The temperature of the scan mirror must be monitored versus orbital parameters to determine whether the correction is dependent on orbital position.

4.2.2.1 QA Indicators Post-Processing

Scan Angle Dependence: We can look at the residual scan angle dependence by averaging the mean scan-angle-dependent radiances, rad_scan_stats(Mean), over all granules within a day. Plot this average versus scan angle for the 17 reference channels, normalized to the value at nadir. This plot should have no dependence with scan angle unless the scene is not Lambertian or is polarized.

Orbital Dependence: We can determine the orbital dependence of the radiometric correction by plotting the radiometric offset as dependent on the input coefficients and the scan mirror temperature as measured throughout the day. A plot of the correction at the end of scan in units of brightness temperature versus orbital position for 17 reference channels is required.

4.2.3 OBC Blackbody Telemetry

The blackbody temperature and signal levels obtained while viewing the blackbody will be tracked and monitored. We do not expect significant contamination of the blackbody to affect the emissivity or the temperature sensing circuitry. However, we must be aware of the following behaviors:

1. The effects of stray Earthshine on the apparent blackbody radiance. The blackbody is not ideal; it is possible for Earthshine to reflect off the blackbody surfaces or regions around the blackbody affecting the calibration. We will then monitor the statistics on the counts (or signals) obtained while viewing the blackbody as dependent variables. Independent variables are orbital position, scan mirror temperature, and scan head temperature.
2. The measurement of the temperature of the blackbody involves several influences. Temperature gradients in the instrument could lead to orbital fluctuations of the blackbody. Electronics temperature could affect gain and calibration of the circuitry to a small degree. We will then monitor the temperatures of the blackbody as dependent variables agains the above-noted independent variables.
3. There are four temperature sensors on the blackbody; they may not all behave the same way in orbit. For this reason, we must monitor their "relative" behavior to ensure there are no sensors behaving irregularly.

4.2.4 Gain Tracking

The first-order conversion of Level 1A detector counts into radiances is a linear transformation; that is, applying an offset and gain. (Second order corrections are also applied and will be discussed later.) The algorithms for doing this are given in the Level 1B ATBD (Reference 2). Monitoring the gain and offsets allows us to determine whether there is optical or electrical degradation of the AIRS instrument.

There are several concerns that can be addressed by looking at the gains and offsets:

1. Is there a systematic degradation in instrument transmission (e.g., icing)? This would be apparent as an increase in the radiometric gain of the instrument (radiance/counts). The dependent variables would be the gain and the gain limits. The independent variables would be time and spectrometer, FPA, and scan mirror temperatures.
2. Are there orbital effects that would influence the radiometry of the instrument? We may see some cyclical oscillations with orbital position over time (for example, due to radiation near the South Atlantic Anomaly). Dependent variables would be the gains and the offsets. Independent variables would be orbital parameters.
3. Are there short-term fluctuations in the instrument gain (that is, over timeframes less than one granule)? We would see this as an increase in the fit deviation errors. This could affect the calibration accuracy in a significant way. We will then track the gain and offset fit statistics versus the orbital environment and the instrument environment.

4.2.4.1 QA Indicators Post-Processing

Image Evaluation: Plot the temperature (from N_sc_ltd) versus latitude and longitude for each day for the 17 limited reference channels. The display may follow a standardized routine used by the database system for browsing data. There will be 90 × (135 × 240) pixels × 17 graphs.

Scan Line (Short Term) Dependence: Plot the average system gain normalized to the system gain at the beginning of the day versus scan line time. Calculate the average system gain as the mean of the gain from the S1 reference detects. Look for high-frequency modulation of the gain with this data (that is, within a granule).

Daily Variation: Plot each module's average gain for each granule, normalized to the first granule of the day. This will result in 17 plots on a single graph. This should tell us if there are any daily systematic variations.

Annual Variation: Plot each module's average gain for each day, normalized to the first day.. This is the equivalent of the Daily Variation Plot, only over a longer time scale.

Orbital Dependence: Plot the average system gain for any granule divided by the average system gain of the first granule in the day versus latitude. See if there are any systematic variations with orbital position.

Saturation Detection: Report in file format the number of blackbody raw data numbers out of limit, input_bb_counts(Num_hi, Num_lo) or input_bb_temp(Num_hi, Num_lo), any time they are not zero for any valid channel and the Calibration Status Word has determined L1B to be valid. Send an automated message to the AIRS Calibration Team that an out-of-bounds condition has taken place and requires immediate attention. Messages should be sent in groups of 3 hours worth of granules.

Channel Dependence: Plot the mean gain for any given granule divided by the gain for any reference granule versus channel. This will allow determination of channel-dependent gain stability.

4.2.5 Noise Monitoring

The Level 1B software produces QA Indicators assessing the noise level in the AIRS instrument.

There are a few concerns that must be addressed by monitoring these parameters, including:

1. The noise levels or behavior may increase over time with degradation of detector and/or electronic systems. The independent parameter will be time on a scale of months to years.
2. With time, there may be degradation of the optical transmission that will affect the NEN. This will also show up as an increase in gain (and a decrease in responsivity).
3. There may be degradation with particular orbital conditions, such as radiation. The independent variables will be the orbital environment.
4. There may be a dependence on instrument temperature. Independent variables will be the instrument environment (in particular, spectrometer temperature).
5. Effects due to changing focal plane temperature. In particular, the noise levels of the PC bands will be highly temperature dependent. Independent variables will be focal plane temperature.

4.2.5.1 QA Indicators Post-Processing

Daily Variation: Plot each module's average NEN for each granule, normalized by the NEN of the first granule in the day. This will result in 17 plots on a single graph. This should tell us if there are any daily systematic variations.

Annual Variation: Plot each module's average NEN for each day, normalized by the NEN of the first day. This is the equivalent of the Daily Variation Plot, only over a longer time scale.

Orbital Dependence: Plot the average system NEN for each granule, normalized by the NEN of the first granule in the day averaged over all valid channels versus latitude and longitude. See if there are any systematic variations with orbital position.

Saturation Detection: Report in file format the number of out-of-limit NENs, nen_stats(Num_hi, Num_lo), any time they are not zero for any valid channel and the Calibration Status Word has determined L1B to be valid. Send an automated message to the AIRS Calibration Team that an out-of-bounds condition has taken place and requires immediate attention. Messages should be sent in groups of 3 hours worth of granules.

Radiance Statistics: Plot the radiances, rad_stats(Mean), in units of temperature, averaged over all scans within a granule and for all granules within a day for all valid channels (valid_chans). Plot the standard deviation of the radiances, rad_stats(Dev), averaged over all granules within a day for all channels. These are highly scene dependent terms and are of uncertain utility for calibration purposes.

4.3 Spectral Calibration

The objectives of the on-board spectral calibration are to determine the band centers and band widths of each of the airs infrared channels, and to determine the phase of the entrance filter channel spectra ("fringing"). For details of the methods used to determine the AIRS Spectral Response Functions (SRF's), please refer to the AIRS Level-1B IR ATBD (Reference 2), the AIRS L1B IR Algorithm and QA Processing Requirements (Reference 6) and the SRF report (both contained in Reference 10), and the Channel Spectrum Report (Reference 13). AIRS relies heavily on the use of upwelling Earth Scene radiance spectra for spectral calibration. An on-board spectral reference source (OBS) consisting of a thin coating (about 25 microns thick) of Parylene on an otherwise low emissivity substrate is also observed once per scanline. Because the spectral features are so much wider in the OBS spectra than in the upwelling scene spectra, the OBS calculations will be used only to provide a "sanity check" on the true spectral calibration (the upwelling feature processing).

4.3.1 Reference Spectrum Selection

The Level 1B spectral calibration software depends on the selection of the correct upwelling radiance profile (pre-calculated) against which to correlate the observed upwelling radiances. This choice is based on the latitude of the granule, the season, whether it is day or night, and whether the granule is mostly over land or sea. We have the following concerns:

1. Failure to use the correct reference spectrum could introduce systematic frequency biases into some detector arrays due to slight differences in feature positions in the reference spectra.
2. Different conditions require fitting to different features. Failure to use the correct upwelling features would result from using the wrong reference spectrum, introducing increased uncertainty, and possible bias.

4.3.1.1 QA Indicator Post-processing

Monitor the individual climatology selected for each granule, and verify that the climatology used was the expected one, based on the geolocation and time fields. Errors (apparent mis-matches) will be flagged in daily summary reports.

4.3.2 Cloud-free Feature Identification

The Level 1B spectral calibration software selects cloud-free footprints, on a feature-by-feature basis, to be averaged before being fit to upwelling radiances. The possible problems associated with including too many cloudy footprints are several-fold:

1. Adding footprints with washed-out spectral features to the average will decrease the signal to noise ratio, increasing the uncertainty of the spectral calibration.

2. Some types of clouds (including cirrus) are known to have non-gray spectral characters. While the associated features are very broad compared to the upwelling atmospheric absorption and emission features, the underlying slope they introduce could create a slight bias for those upwelling features lying on the most rapidly varying portions of the cloud spectra.
3. Some level of cloudiness will be undetectable, at least on a per-footprint basis. It is remotely possible that some upwelling scene features (called "candidate features" in the AIRS L1B IR ATBD, Reference 2) may be so sensitive to clouds that they must be excluded from the fit for lack of our ability to identify low cloud amounts.

4.3.2.1 QA Indicator post-processing

Create weekly scatter plots, for each of the candidate spectral features, of feature contrast mean versus feature fit position. Fit a line to the data. Identify statistically significant non-zero slopes in the weekly summary reports.

4.3.3 Upwelling Feature Fitting

Central to the AIRS in-orbit spectral calibration is the determination of the positions (in physical units) on the focal plane assembly of spectral features of known frequencies. Because these features were selected on the basis of simulated data, they may show unexpected behavior in orbit. Potential causes of concern include:

1. Variable cloud type and amount could introduce variability and/or biases into some observed feature locations.
2. Other types of atmospheric conditions could introduce variability and/or biases into some observed feature locations.
3. The model atmospheres on which the upwelling reference spectra are based could be significantly different from those actually observed.
4. The upwelling reference spectra could be based on faulty spectroscopy, physics, or simulation.

4.3.3.1 QA Indicator Post-processing

Modality: Create daily histograms of the calculated position of each upwelling feature. Verify quasi-Gaussian shape visually. Calculate mean, peak, and width of the daily histogram distributions, for each upwelling feature.

Daily Variation: Create daily plots of calculated positions of each upwelling feature versus time. Major orbital variation will be visible, if present. Any sufficiently large trend (e.g., from orbital effects or a change in instrument operation mode) will be apparent in one day of data, visually inspected.

Orbital variation: Monthly, calculate the power spectrum of the time series of observed positions, for each of the upwelling features. Report relative power at orbital, daily, and repeat-cycle periods, relative to the width of the histograms (fit uncertainty). Identify and report any other periods with significant power.

Mission Variation: Plot the daily means, peaks, and widths of the histograms, over the life of the mission. This will clearly reveal any long-term trends.

Covariance: Daily, calculate the covariance matrix for the feature shifts. Identify "unhelpful" upwelling features by finding minima in the covariance matrix.

Climatology Dependence: Fit feature positions calculated for a single atmospheric “state” will be averaged for each feature. The resultant mean positions will be compared, looking for systematic differences with atmospheric state.

4.3.4 OBS (Parylene) Feature Fitting

While the actual AIRS in-orbit spectral calibration is based on the positions of features in the upwelling radiance spectra, the On-board Spectral Source (OBS) is also used as a "sanity" check on the state of instrument's spectral calibration, and on the spectral calibration algorithms. Although the focal plane fit parameters (see section 4.3.5, below) are the best indicator of spectral reasonableness, they are even more useful after they have been checked against the positions of the individual features on which they are based. Some concerns regarding the interpretation of these positions include:

1. Is there sensitivity to orbital position? Not all features might react (move) in the same way.
2. Can the same trends observed in the upwelling features positions be coaxed out of the OBS fit data?

4.3.4.1 QA Indicator Post-processing

Modality: Create daily histograms of the calculated position of each upwelling feature. Verify quasi-Gaussian shape visually. Calculate mean, peak, and width of the daily histogram distributions, for each upwelling feature.

Daily Variaion: Create daily plots of calculated positions of each upwelling feature versus time. Major orbital variation will be visible, if present. Any sufficiently large trend (e.g., from orbital effects or a change in instrument operation mode) will be apparent in one day of data, visually inspected.

Orbital variation: Monthly, calculate the power spectrum of the time series of observed positions, for each of the upwelling features. Report relative power at orbital, daily, and repeat-cycle periods, relative to the width of the histograms (fit uncertainty). Identify and report any other periods with significant power.

Drift analysis: Plot the daily means, peaks, and widths of the histograms, over the life of the mission. This will clearly reveal any long-term trends.

4.3.5 Focal Plane Fitting

The reduction of the individual feature positions to a focal-plane-wide fit provides the best summary information on the status of the AIRS spectral stability. The associated QA indicators are used to determine:

1. How stable are the calculated frequencies? Are any trends observed? What kind of variability is observed?
2. Are the calculated frequencies "close" to the reference set?
3. Are significant biases observed in fit position residuals?
4. Does the Parylene fit track the upwelling fit?

4.3.5.1 QA Indicator Post Processing

Daily variation: Make a time series of the focal plane offset and delta focal length, for both upwelling and Parylene fits. Look for obvious trends, variability, or differences between the upwelling and the Parylene fits.

Daily summary: Make histograms of the focal plane offset and delta focal length, based on upwelling and Parylene focal plane fits. Verify pseudo-gaussian shape visually. Calculate mean, median, width for each of the four.

Drift analysis: Plot the daily means, peaks, and widths of the two upwelling histograms, over the life of the mission. This will clearly reveal any long-term trends.

Orbital variation: Monthly, calculate the power spectrum of the time series of the calculated focal plane offset and focal length shift, as calculated from upwelling spectra. Report relative power at orbital, daily, and repeat-cycle periods, relative to the width of the histograms (fit uncertainty). Identify and report any other periods with significant power.

Feature residuals: For each granule, for each upwelling feature, calculate the difference between the observed position feature, and the calculated position feature (based on the new focal plane offset and focal length shift).

Daily produce a histogram for each feature (240 samples). Verify quasi-Gaussian shape visually. Calculate the mean, peak, and width of each histogram. Significantly non-zero means or peaks indicate that the feature is an outlier, requiring a modification to the focal plane model and/or the feature database.

4.3.6 Channel Spectra Determination

The Fabry-Perot interference effects from the AIRS entrance filters are determined in three ways:

- Pre-launch SRF analysis.
- Special test AIRS-C3.
- By monitoring the entrance filter temperature.

Of these three, only the latter, monitoring the entrance filter temperature, falls in the category of L1B QA processing. We have the following concerns regarding in-orbit determination of channel spectra:

1. What if the channel phase doesn't match that predicted by the entrance filter temperature?
2. What if the entrance filter temperature changes enough that the shifted channel spectra significantly perturb the SRF's?

4.3.6.1 QA Indicator Post-processing

Out-of-bounds conditions (limit-checking) of the entrance filter temperature will be reported in daily summary reports.

4.4 Spatial Calibration and Scene Uniformity

The AIRS instrument is designed to minimize the dependency of each channel on the spatial variability in the upwelling radiance. However, there is some residual nonuniformity that may exist. There are several channels on AIRS that have nearly identical spectral responses and should produce the same signal response insomuch as they have the same spatial response. The algorithms used for spatial calibration make use of these channels extensively.

We will monitor the Cij metrics over time to determine if there is any systematic degradation of the spatial response function. This would only occur if there were some significant misalignment in the instrument. To date, we have not seen any dependence on the spatial response function with instrument temperature, vibration or other instrument environmental parameter.

4.5 VIS/NIR Radiometric Calibration

The primary metrics for monitoring the radiometric calibration of the VIS/NIR system are the correction terms routinely generated from vicarious calibration against known ground targets and data from the Moderate Resolution Imaging Spectroradiometer (MODIS). (See the Level 1B ATBD, Part 2 for a discussion, in particular, note the terms gamma-g and gamma-M in Eq. 2-15.) Furthermore, health of the on-board bulbs is monitored by trend analysis of the ratio of the smooth gains from bulbs i and j, Kij, described in the Level 1B ATBD, Part 2, Section 2.5.4.1.

5 Engineering Telemetry Monitoring Plan

5.1 Objectives

The objectives of monitoring the telemetry data from AIRS in the high rate data are several:

- To assess and report the current operating state of the instrument.
- To assess and report the current health of the instrument; provide a flag to L1B and L2 science data processing for every scan that contains telemetry values outside acceptable limits.
- To provide automatic messages to responsible individuals for instances of telemetry parameters changing from acceptable to warning or critical conditions.
- To develop and publish trend plots of selected parameters to reveal potential slow degradations as well as orbital and seasonal dependencies.
- To provide an archive of operating state and health reports that can be accessed well after the fact to support long-term analyses of AIRS science data and data products.

5.2 Telemetry Parameters

All telemetry parameters that are active given the current operating configuration will be processed for health status. Additional parameters will be derived from the telemetry, such as temperature differentials and power (i.e., volts and amps). Selected health status data will be reported in summary tables. Selected telemetry parameter values will be presented in trend plots. Key parameters will be monitored by subsystem as described in the following subsections.

5.2.1 Configuration State Determination

This process determines the redundant configuration of AIRS, excluding detector A/B gain coefficients (however, the A/B Gain and Circumvention table checksum is reported), and the state of selected basic functions, such as the scanner mode, whether or not 2nd stage and OBC temperature control is on, photometric calibrator lamp states, Sensor Electronics Module (SEM) test pattern on/off and the state of the earth shield and its latch mechanism. Configurations are determined and stored for each scan and a summary text report file is generated.

5.2.2 SEM and FPA Setup Determination

This process determines the current set up of SEM and Focal Plane functions, including module powering, over-temperature power control, bias generator selected and detector bias voltages and integration times, subsample weighting in the footprint summation process, Circumvention on/off and Circumvention Base Threshold, and PC detector offset value. Configurations are determined and stored for each scan and a summary report is printed.

5.2.3 Temperature Monitoring

Temperatures will be compared to expected, warning and critical limits. Expected values will depend on the current operating conditions. Warning and critical limits have been defined by thermal analysts. Temperature differentials will be determined and compared to expected values based on test data acquired at BAE Systems and TRW during ground testing. Differentials will be flagged if outside expected limits.

5.2.4 Cooler Performance Monitoring

The following cooler performance parameters are required for long term trending: cold finger temperature, compressor temperature, cold plate temperature, compressor peak stroke (side A and side B), compressor drive current, (side A and side B), optical bench temperature and cooler vibration level.

5.2.5 Scanner Performance Monitoring

Determine scan mode and servo PID parameters and compare to required values by mode. Determine statistics of mirror positions by footprint for current scan mode and compare with expected values. Determine scan motor drive current and compare with expected values for current mode. Trend scan motor drive current, nadir position jitter and nadir position error for scanning mode.

5.2.6 Chopper Performance Monitoring

Determine statistics of parameters chopper phase error, amplitude, drive current, and servo error. In addition, determine the amplitude and phase setting (commanded) and the supply voltages to the servo circuit. Trend phase error and drive amplitude.

5.2.7 Second-Stage Temperature Control Monitoring

Determine heater current, current drift and rms noise. Determine set point to 2nd stage radiator temperature differential. Trend heater current and set point to 2nd stage radiator temperature differential.

5.2.8 OBC Control Monitoring

Determine heater current, heater current drift, and heater current RMS noise. Determine 308 K (fixed set point) to Temperature Sensor 1 (active A or B) temperature differential. Trend heater current and 308 K to Temperature Sensor 1 temperature differential.

5.2.9 AMA Movement Telemetry

Determine and report position of each actuator, position and tilt of the Schmidt mirror and state of each actuator. Maintain log of absolute positions and states for life of mission.

5.2.10 Photometric Calibrator Lamps

Determine current in active lamp. Calculate photometric Gain for active lamp. Trend lamp current and photometric Gain for each lamp.

5.2.11 Power Supply Monitoring

Supply voltage and currents will be compared to expected, warning, and critical limits. Expected values will depend on the current operating conditions. Warning and critical limits are provided in Reference 4. Determine RMS noise on voltages. Trend voltages, currents, and RMS noise.

5.2.11.1 Reference and Ground Potential Monitoring

Compare reference and ground potentials with expected values. Flag when change is significant enough to warrant a change of engineering telemetry DN to engineering units conversion coefficients. Determine rates of change and predict when conversion coefficients likely will need changing.

5.2.12 Main Processor Performance

The parameters are the time (in 2^{16} sec increments) that the processor spends in each footprint accomplishing its assigned tasks (both inside and outs the 1428-Hz interrupt periods). When this value exceeds 22.4 milliseconds, a bit in telemetry SW Status Word is set for "Task Overrun." This is not necessarily an error; however, it does mean that the set of activities associated with the next footprint will get off to a late start. Currently, a few known "busy" footprints almost always have an overrun. This parameter (one of each footprint) should be monitored over time to see whether the instrument control process is gradually getting "fatigued."

5.3 Telemetry Processing

5.3.1 Low level processing

Low level processing of telemetry data will be performed on the Product Generation System in the Level 1B software. As discussed in section 4.1, the Level 1B PGE computes statistics on the scan-by-scan data obtained in from L1A. The statistics include mean, max, min, standard deviation, location of max and min within the granule and number of out of limit conditions of high and low limits. These data will be routinely monitored for orbital dependencies.

In addition to the granule statistics, starting with telemetry data converted to engineering units, produce a file of redundancy-configuration codes of all redundancies and commanded functions. Starting with the engineering units and the redundancy configuration code data, produce a file of health code for every active telemetry parameter for every scan line. The health code value assignments should be:

0 = N/A or off
1 = Critical Low
2 = Warning Low
3 = Acceptable Low
4 = Expected Range
5 = Acceptable High
6 = Warning High
7 = Critical High

Starting with the health codes for each scan, monitor health status codes for transitions from expected and acceptable (codes 3, 4 and 5) to warning (codes 2 and 6) or from expected, acceptable and warning (codes 2, 3, 4, 5 and 6) to critical status (codes 1 and 7), and the reverse. Write transitions to the L1B file. All L1B files will be routinely archived at the Team Leader Science Computing Facility (TLSCF).

5.3.2 Intermediate Level Processing

As discussed in section 4.1, a Level 1C processor will summarize granules over an entire day and produce a Level 1C engineering product. This will have the daily statistics on all engineering telemetry and identify all states in warning or critical status.

Starting with archived telemetry values, we will develop trend plots for a selected set of parameters and start and stop times. The software will read the Level 1B or Level 1C and provide means for orbital and seasonal averaging of data (orbital averaged data or seasonal averaged data) in accordance with user request.

5.3.3 High-Level Processing

We plan to write the configuration and health data summarized for the most recent day (see previous section) to a web page on a NASA WAN or the internet. We will develop a capability to plot parameter health code values for any specified time interval for all such parameters which reach warning or critical levels during the interval.

Starting with the health codes transitions monitor file(s), for the change to a warning or critical in a specified period (say 12 hours), the higher level processor will send an e-mail summary message to interested parties. The address lists will depend on the parameter and whether the transition is to warning or to critical. After the specified period of time has elapsed (for example, 12 hours), the processor will send an e-mail summary message to the same parties for the parameters that have returned to their previous safer level of status (e.g., red to warning or warning to acceptable).

Starting with the Level 1C values, trend plots will be developed for a pre-selected subset of parameters and display to a web page on a NASA WAN or the internet. Interactive entries on the web page will specify the start and stop times for the plots.

6 Use of Earth Scene Data for Calibration

Validation for Level 2 data products is covered explicitly in the AIRS Validation Plan (Reference 5). In some cases, however, we would like to use the external scene information to verify the AIRS instrument calibration and the Level 1B data product.

6.1 Radiometric

At "first light" we will obtain the first infrared views of Earth by the AIRS instrument. During this early phase of instrument operation, the accuracy of the measurements will be assessed based on limited knowledge of instrument and data software performance. Several issues will affect the response of the instrument and limit the conditions for which relatively unambiguous validation information is extracted. Some of the instrument issues include scan angle dependent view factors, uncertainties in the spectral response of the detection system, and incomplete knowledge of the on-board calibrators.

In order to carry out initial checks of the accuracy of the radiation measurements and minimize calibration uncertainties, simple validation techniques will be implemented that operate in "window" region (spectral regions with little atmospheric absorption). The wavelength resolution of the instrument varies from 0.5 cm^{-1} at long wavelengths to about 2 cm^{-1} at short wavelengths. In the super-transparent 4-micron region, there are several candidate window regions broad enough that small uncertainties in the assignment of spectral wavelength to detector channel do not introduce large errors in the equivalent blackbody radiance. Within these regions, effects of atmospheric absorption are small even under moist conditions. Hence, the radiation at the aperture of AIRS should be very similar to the radiation leaving the surface. For the AIRS detection wavelengths, the sea surface emissivity is near unity. Away from strong ocean current regimes, the sea surface is relatively uniform in temperature. Because of these reasons, early validation techniques will check the radiances in AIRS window channels against surface marine observations and the National Center for Environmental Prediction (NCEP) forecast analyses.

Comparisons of L1B radiances with surface marine observations will provide the basis for initial validation and continuous checks of the instrument calibration software. Radiances in several window regions located between 800-1000 cm^{-1} and between 2500 and 2700 cm^{-1} will be compared to weekly sea surface temperature climatology derived mainly from ship track data and satellite measurements. The radiances will also be compared to the NCEP/European Center for Medium Range Weather Forecasting (ECMWF) surface analyses and match-ups for a select set of drifting buoy observations, which are available on a daily basis.

The technique is statistical and operates on entire granules (12,500 footprints). Relatively clear ocean regions (granules) are first identified using GOES VIS/IR imagery. Using either the NCEP analyses or standard atmospheric profiles, AIRS Top of Atmosphere (TOA) radiances are "adjusted" to the surface to account for the spectral dependence of atmospheric continuum absorption. Surface emission effects are also factored into the radiance adjustments. The radiances adjusted to the surface are compared to the observed SST or NCEP surface analysis. This technique was recently demonstrated using global simulation data sets derived from the NCEP Aviation Forecasts for September 13, 1998 and December 15, 2000. Simulated AIRS radiances at 2616 cm^{-1}, a "super transparent" short wave channel, were compared with SST and NCEP surface analyses.

The histograms of Figure 17 were obtained from differences between reliable SST weekly climatology and simulated radiances over tropical ocean limited to the nighttime satellite pass, to avoid daytime affects of short wave scattering of solar radiation.

Four different granules were processed for this figure for two different dates, December 15, 2000 and September 13, 1998. The methodology was found to work very well for basic evaluations of instrument performance with an uncertainty of about 1 K. Residual cloud contamination and sea surface skin-bulk temperature differences contribute to this level of uncertainty. Under very cloudy conditions the technique does not work well, as shown by the data for granule 99 in the September, 1998 simulation. Because AIRS has very high spectral resolution and atmospheric absorption in some of the window channels is very small (0.1-0.3 K), AIRS has the potential to measure with a precision approaching 0.1 K. More refined analysis techniques are being developed to meet this challenge. These techniques will require very stringent cloud screening algorithms.

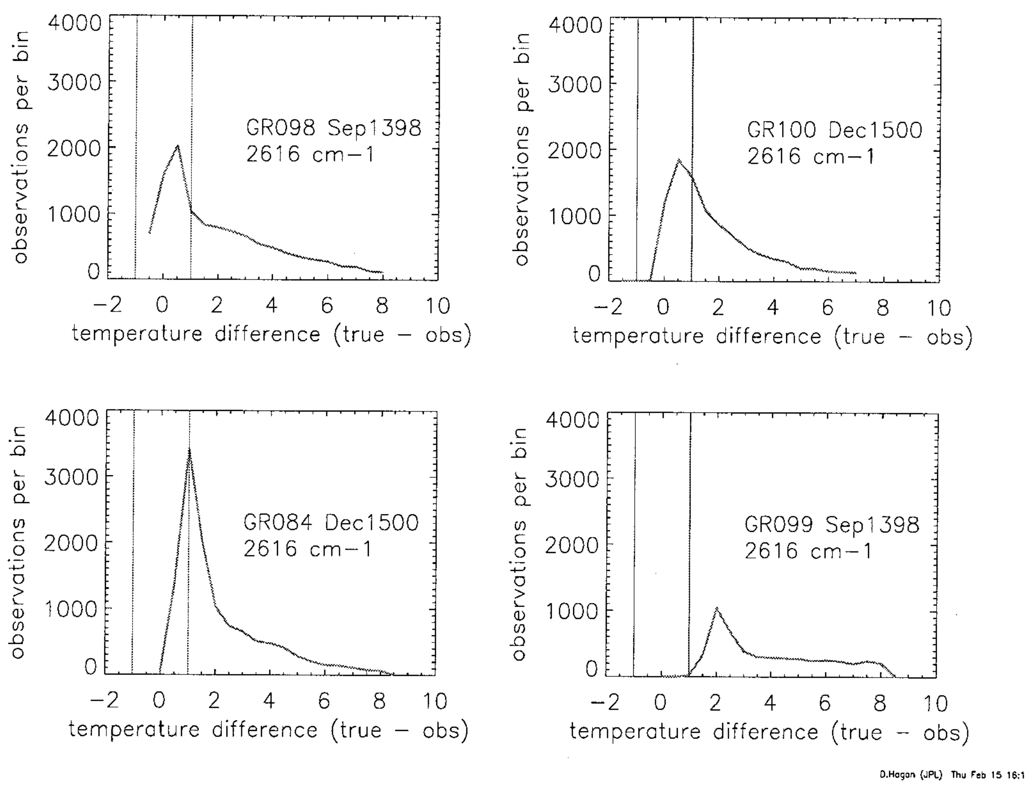


Figure 17. Histograms of the difference between SST and AIRS simulated radiances for four different granules for a window channel located at 2616 cm^{-1}. The cloud contribution to the simulated radiance is larger for granule 99 (lower right) than the other cases. The granules were selected from tropic and sub-tropic ocean regions.

6.2 Spectral

Section 4.3 discusses the required processing of L1B QA indicators for spectral calibration monitoring purposes. This section discusses the requirements for in-orbit spectral calibration that cannot be accomplished with just the L1B QA indicators. (Additional L1B radiances are required.)

6.2.1 Optimization of Upwelling Features

Among the primary inputs for the spectral calibration calculation is the list of upwelling features, with their associated properties. Refining and optimizing this list of features will be a major component of the in-orbit spectral calibration activities. Each component of the upwelling features needs to be optimized individually.

6.2.1.1 Verification of Feature List by Reference Spectrum

Concern: Some upwelling atmospheric features may be useful under some atmosphere conditions, but not others. Including features which, under some atmospheric conditions, are too variable (in frequency) or which never satisfy the spectral contrast criteria is counter productive. Such features should be excluded from the focal plane fit on the basis of the atmospheric ("climatological") state: the latitude of the granule, the season, whether it is day or night, and whether the granule is mostly over land or sea.

Unlike the other components of the upwelling features database, the dependence of feature position with atmospheric "condition" (the latitude of the granule, the season, whether it is day or night, and whether the granule is mostly over land or sea) can be determined solely from analysis of L1B QA indicators. The procedure for doing so was described above, in section 4.3.3.1, Climatology Dependence.

6.2.1.2 Verification of Feature Contrasts

Selecting the optimal contrast cut-offs for clear footprint selection is prone to two types of error:

1. Setting the contrast requirement too high. In this case, too few footprints are added to the average, and signal to noise suffers.
2. Setting the contrast requirement too low. In this case, features with low contrasts are added, and again signal to noise is compromised.

Because the atmospheric simulations on which we were relying pre-launch are known to be unreliable in their simulation of clouds, an empirical approach using real data is preferred.

Desire: For each upwelling spectral feature, for each climatological case, we wish to determine the optimal value for the spectral contrast cut-off value.

Approach: From a month of data, select those granules with the desired climatological conditions. Then, for each upwelling feature, run the spectral fitting software in the testbed using many different values of the spectral cut-off value. Calculate histograms of calculated position for each feature. Choose that cut-off value, for each feature, which has the narrowest histogram.

Verify the results by doing the same calculations on a different month's data.

6.2.1.3 Verification of Feature Channels

The position calculated for an individual spectral feature depends weakly on which exact set of points around that feature are fit to. Including undesirable channels in the calculation can happen in three distinct ways:

1. A bad channel could be used. If a channel is too noisy, it detracts from the fit quality, even if that channel is reasonably well calibrated.
2. Too many channels could be used. Fitting is best done to points where the radiance profile is varying at the greatest rate. By including channels where the radiance is nearly constant, the noise on the individual measurements detracts from the fit quality.

3. Too few channels could be used. Given several points at frequencies with high sensitivity (where the radiance is changing rapidly), failure to include all the good points imposes a needless hit on signal to noise.

Desire: Choose the set of points, for each feature, for each climatology, which optimizes the feature fit.

Approach: From a month of data, select those granules with the desired climatological conditions. Then, for each upwelling feature, run the spectral fitting software in the testbed using many different sets of points to which to correlate. Calculate histograms of calculated position for each feature. Choose that cut-off value, for each feature, which has the narrowest histogram.

Verify the results by doing the same calculations on a different month's data.

6.2.1.4 Verification of Feature Weights

The weight given to each upwelling feature for the focal plane fit is inversely proportional to the uncertainty of that feature's fit. With new contrast criteria (from 6.2.1.2, above) and new feature fit points (from 6.2.1.3, above), new static feature fit uncertainties can be estimated (from the histogram widths). New weights are assigned based on these new uncertainties, and the month of test data are reprocessed, verifying the improvement to the focal plane fits.

6.2.2 Optimization of OBS (Parylene) Features

Like the upwelling radiance features, selection of the specific spectral features in the the On-Board Spectral Calibrator (OBS) can have an effect on the accuracy of the focal plane fits.

Unlike the upwelling radiance features, however, the OBS (Parylene) features were well sampled during pre-launch testing. Because the Parylene features were actually measured, rather than modeled, it is not anticipated that the specifics of the feature selection, feature channels, or feature weights will change in-orbit.

In the event that the Parylene fits do not work well in orbit, we still have the capability of revising the OBS feature database in a method analagous to that described above, for the upwelling features, but without the breakdown by climatological condition.

6.2.3 Optimization of the Focal Plane Map

In addition to the knowledge of upwelling feature frequencies and positions on the focal plane, central to the AIRS in-orbit spectral calibration is the knowledge of the positions of the detector elements on the focal plane assembly (FPA), relative to one another. This knowledge is referred to as the focal plane map.

Because the number of upwelling radiance spectra observed by AIRS in orbit will be so much greater than the amount of pre-flight spectral data acquired, we will have the ability to refine our knowledge of the focal plane map. This will be accomplished in two ways:

1. Using position-fit residuals to correct detector array offset positions.
2. Using empirical variational techniques to calculate corrections to focal lengths and refine detector array offset positions.

6.2.3.1 Position Fit Residual Corrections

Errors in the detector-array-position offsets will be manifested as a non-zero mean in the distribution of feature-position residuals (see Section 4.3.3.1, Upwelling Feature Fitting QA Indicator Post-processing). Any such non-zero means translates directly as corrections to the focal plane model.

6.2.3.2 Variational Analysis

While the feature-position-fit residuals give an excellent indication of the corrections needed to the array offsets, they provide little insight into the errors in the focal lengths assigned to each detector array, even for those detector arrays containing multiple spectral features. Therefore, the approach taken will be to run a month of data through the testbed, applying a variation to the focal length to each detector array. The magnitude of the variations must be large enough that the effects of the variation are seen, yet small enough that the variation remains within the linear range. Those detector arrays that have accurate values for their focal lengths will be seen to show little variation (near the minima of their residuals), while those arrays that have larger errors in their focal lengths will demonstrate an obvious reduction (or increase) in their fit residuals.

The variations will again be applied with the same magnitude, but opposite signs, to verify that the residuals are within the linear range before the correction is applied. New focal lengths are calculated for the appropriate detector arrays. With the new focal plane lengths, feature-fit-position residuals will be recalculated and reapplied (see Section 6.2.3.1).

6.3 AIRS IR Geolocation

Validation and accuracy assessment for the AIRS geolocation process require detection and geolocation of independent Earth surface features. A technique has been developed, patterned after the CERES/ERBE approach (Reference 15), to detect coastline crossings and compare their geolocated positions with accurate coastline maps. Two or more window channels (for example, 882 cm^{-1} and 2500 cm^{-1}) are used to look for a characteristic signature when scanning high-thermal-contrast desert adjacent to ocean scenes. While the ocean maintains a relatively constant diurnal temperature, the desert temperature fluctuates, resulting in a diurnal reversal of the slope of the coastline signature. Visual and IR images from GOES will be used to select clear areas over a set of validation targets. The initial targets that will be used are those used by CERES and ERBE, which include Baja California, Australia, Libya, the Arabian Peninsula, and South Africa. A cubic equation is fit to the scan-line signature and the inflection point of this fit is assumed to represent the exact location of the coastline. The latitude and longitude of each inflection point are determined by linear interpolation between the adjacent data points. To reduce extraneous data due to the rapidly changing thermal contrast of inland terrain, only data predicted to be within 25 km of the coastline is processed. Latitude and longitude errors are determined for each scene by minimizing the least squares distance of the ensemble of crossings to the coastline map. These errors are transformed into in-scan and cross-scan errors for correlation with possible instrument error sources. In-scan and cross-scan location errors will be determined by averaging individual scene samples collected over extended time periods.

6.3.1 Initial Quick Check

During the first week that operational data is available, one or two clear target sites will be selected and the data from these sites processed to provide an initial rough look at the pointing accuracy. Rough estimates of both longitude and latitude errors and in-scan and cross-scan errors will be provided for these targets.

6.3.2 Initial Evaluation of Geolocation Errors

To provide the initial evaluation of instrument pointing accuracy, data will be collected and analyzed for 32 days. Because the satellite has a 16-day repeat cycle, this will provide scenes that are scanned twice at the same scan angle. If we assume that 50% of the scenes are adequately clear, there will be an average of approximately 2.5 scans per day of the five target areas, which will yield approximately 80 sets of error numbers for the individual scenes. This should be adequate to provide accurate average location errors and may also provide, by appropriate averaging, some scan-dependent error information.

7 In-Flight Calibration Operations Requirements

The processing of calibration data places significant requirements on the operations of AIRS and the AIRS Data Processing System. Operational requirements are primarily in response to the Special Tests for Calibration. These tests require commands to be sent to the spacecraft for exercising the AIRS subsystems. Data obtained during these special tests must be expedited and processed by the TLSCF and ultimately the DAAC. These issues are discussed below. Finally we present here the plan for operational monitoring of the QA indicators obtained from the L1A and L1B PGS.

7.1 Operational Requirements for Calibration

The AIRS Operations team is responsible for executing the Special Test Procedures for Calibration. These are discussed in detail in section 3. The requirements for the procedures are given in section 3 and implemented in AIRS command language as best determined by the Operations Team.

The AIRS Calibration Team (ACT) will be present at the command center when the special test for calibration procedures are executed. Demonstration of the effectiveness of the procedures in producing the desired sequence of commands is demonstrated prior to launch. This allows us to monitor the real time low rate engineering telemetry through the Instrument User Terminal at the EOS Operations Center. Some sequences will be run without real time confirmation. Then it will be up to the AIRS Calibration Team to confirm successful operation. To do this in timely fashion, we have established expedite requirements.

7.2 Processing and Expedite Requirements

All data used by the AIRS Calibration Team must first be processed to some level prior to use. This processing level is discussed below and most likely will be performed by the AIRS TLSCF for the first two years. After this time, data may be obtained directly from the DAAC if the L1A and L1B are accurate and current.

One can see from the schematics of the Special Tests for Calibration that the expedite flag is set in every calibration sequence during the periods when science data is required. This allows rapid evaluation of instrument performance during these periods since in most cases the AIRS will not be operational. The Operations team will want quick response as to the effectiveness of the procedures to determine if they need to be repeated or run differently. The expedite flag also facilitates routing of the data to the calibration team. Finally special critical events such as orbital maneuvers, Earth Scene targets of opportunity (including weather phenomenon), or spacecraft high noise and radiation events can be flagged and expedited using the AIRS-C1 procedure.

Table 7 provides a listing of the anticipated data processing requirements for the special calibration sequences. All data in the table are to be expedited. We have listed the duration of the calibration sequence, the number of sequences per test, and the total number of granules we expect we will need for this test. The level of processing required by the calibration team is listed, however, additional processing may be required by the Level 2 PGS. Table 5 gives the processing level possible from any of the calibration sequences. We also list the size of the files, and the total memory usage expected for the test and for the year. We have been conservative on the number of tests expected per year, but have included no margin in the individual test event requirements.

The AIRS TLSCF will be responsible for processing the data to the desired levels, archiving the data at the processed level and archiving the results. In addition to the input data discussed in Table 7, there will be many output files containing intermediate data from computations on the raw data (mostly for reducing the data volume), as well as results files, charts and reports. In our experience with prior data processing systems, the volume of the output files from the calibration team will be much lower (less than 10%) than our input requirements.

Table 7. AIRS Calibration Team Data Requirements. All data in this table to be expedited.

AIRS CALIBRATION TEAM EXPEDITE REQUIREMENTS								
TEST EVENT	Sequence Duration (min)	No. Sequences / test	Total No. Granules (Est.)	Proc. Level C=Calibration S=Science	Size of Files (MB)	Estimated Size / Test (MB)	Number of Tests / Year	Estimated Size / Year (GB)
AIRS-C1: Normal Mode + Special Events	9.00	3	6	L1AS, and L1BS	189.00	1134.00	100	113.40
AIRS-C2: Guard Test	24.00	3	12	L1AC	4.10	49.20	3	0.15
AIRS-C3: Channel Spectra Phase Test	7.00	4	8	L1AC	4.10	32.80	1	0.03
AIRS-C4: AMA Adjust Test	24.00	4	16	L1AC	4.10	65.60	2	0.13
AIRS-C5: OBC Cooldown Test	7.00	15	30	L1AC	4.10	123.00	3	0.37
AIRS-C6: Variable Integration Time Test	15.93	1	3	L1AC	4.10	12.30	3	0.04
AIRS-C7: Space View Noise Test	21.67	5	20	L1AS	59.00	1180.00	3	3.54
AIRS-C8: Radiation Circumvention Test	21.67	5	20	L1AS	59.00	1180.00	3	3.54
AIRS-C9: Scan Profile Test	30.67	2	12	L1AS	59.00	708.00	3	2.12
AIRS-C10: VIS Radiometric Test	6.00	3	3	L1AC	4.10	12.30	27	0.33
AIRS-C11: Warm Functional Test	6.00	1	1	L1AC	4.10	4.10	3	0.01
AIRS-C12: Cold Functional Test	6.00	1	1	L1AC	59.00	59.00	3	0.18
Telemetry Status	6.00	240	240	L1A HREng	0.90	216.00	365	78.84
QA Post Processing	6.00	120	120	L1B QA	0.74	88.30	100	8.83
Total	**184.9**	**407**	**492**		**455.3**		**619**	**211.5**

8 Timeline for Calibration

Calibration is an ongoing process starting at spacecraft Activation and Evaluation (A&E) and continuing through mission completion. We will first establish a pre-launch baseline from data acquired during instrument build and integration with the spacecraft. This baseline will be achieved by running the Special Tests for Calibration. A good fraction of these will be repeated every 6 months. We then plan to regularly monitor the L1A telemetry and L1B QA indicators for instrument health, safety, performance and accuracy.

8.1 Timeline for Special Test for Calibration

During the spacecraft A&E Phase, we will execute the Special Test Procedures for Calibration. We will then be able to compare the in-orbit operation with the pre-flight baseline. All Special Test procedures discussed in section 3.0 will be executed. The timeline for individual special test is already discussed in section 3.2. We anticipate that during flight operations all the special tests will take approximately seven days to execute.

The first execution of the special test occurs just before and during cool down. The remainder occur shortly after cool down, when the AIRS is stable at its nominal operating temperature. This temperature is currently 155K, but will depend on the margin available in the optical bench temperature control system. All tests except AIRS-C11 will be run at this time. If an orbital maneuver, decontamination event or other incident occurs during the life of the program which causes our optical bench temperature to loose temperature control, we will need to re-run the special test procedures in their entirety after re-stabilization.

The special test procedure AIRS-C1 is run most frequently. It initiates the periodic DCR and Lamp 1 operations. DCR occurs every 20 minutes and Lamp 1 every 2 orbits. We will use AIRS-C1 as necessary to expedite certain scene targets of opportunity for processing of the AIRS Calibration Team to ensure accuracy and timeliness of the AIRS calibration. AIRS-C1 may also be used to collect "golden" orbits or days of data for science and calibration evaluations.

Our plan is to run selected calibration sequences periodically to check for changes in instrument response. If we have not changed the temperature of the optical bench and it has maintained control, we need not run all the special test procedures. Assuming no change to optical bench temperature, the following sequences (in addition to AIRS-C1) must be run every six months to ensure proper calibration of the AIRS. The AIRS Project Office reserves the right to execute or not execute any one of the Special Tests for Calibration at any time at the recommendation of the AIRS Calibration Team.

AIRS-C2: Guard Test. This ensures all channels functional and noise levels have not degraded.

AIRS-C5: OBC Float Test. Ensures linearity of the response of the detectors and incrementally improves our knowledge of the calibration.

AIRS-C6: Variable Integration Time. Allows detection of degradation of the analog signal processing electronics.

AIRS-C7: Space View Noise: Assures stability in the nature of the noise (Gaussian or Non-Gaussian).

AIRS-C8: Radiation Circumvention: Allows us to change the radiation Circumvention Levels to reduce impact of radiation events on the noise.

AIRS-C9: Scan Profile: Assures seasonal variations of stray light and earthshine in the space viewport are not influencing the calibration.

AIRS-C10: Lamp Operations: Allows execution of any one lamp for one orbit to verify VIS/NIR long-term stability.

No science data will be available during tests AIRS-C6, C7, C8, and C9. This should only be a loss of a few orbits of data. Also procedures AIRS-C7, C8, and C9 require stopping or changing the scan profile of the AIRS scan mirror. All procedures are required to be fully tested prior to launch and during the A&E phase and, therefore, will not pose significant risk to the program.

8.2 Timeline for Monitoring L1B QA and Telemetry

A set of programs will be developed to regularly display the important L1B QA and Telemetry as defined in Sections 4 and 5 of this document. The programs will first be tested on data obtained at BAE SYSTEMS and TRW. A baseline will be established.

We plan to start by looking at the L1B QA and Telemetry files for out of bound conditions and max and min deviations. Then we will look at the daily files, L1C for the same variation. For parameters which either have wide excursions or even violate their limits, we will plot the individual parameters vs orbital position to see how , where and why they may be changing.

During the first three months, daily reports will be generated; most of these from the summary L1C files. This is when we focus on the short time scale variations due to orbital position and contamination effects. We will attempt to correlate observed degradation (if any) with the instrument environment.

During the first year we will attempt to correlate any long term drifts with seasonal variations. This will involve plotting daily summaries against mission life. Finally over the entire mission life, we will present weekly and monthly reports. All reports will be presented on the AIRS Calibration Team Web Page and in ACT reports where anomalies are found.

Appendix A: Abbreviations and Acronyms

A&E	Activation and Evaluation
ACT	AIRS Calibration Team
ADF	AIRS Design File
AIRS	Atmospheric Infrared Sounder
AMA	Adjustable Mirror Assembly
AMSU	Advanced Microwave Sounding Unit
ATBD	Algorithm Theoretical Basis Document
ATCF	AIRS Test and Calibration Facility
BAE	British Aerospace and Electronics Sanders
BB	Blackbody
Cij	Spatial Co-registration between channel i and channel j
CPT	Comprehensive Performance Test
DAAC	Distributed Active Archive Center
DCR	DC Restore
DFN	Design File Memo Number
ECMWF	European Center for Medium Range Weather Forecasting
ECS	ESDIS Core System
EMI/EMC	Electromagnetic Interference, Electromagnetic Conduction
EOS	Earth Observing System
EV	Earth View
FPA	Focal Plane Assembly
FRD	Functional Requirements Document
GSS	Ground Support System
HgCdTe	Mercury Cadmium Telluride
HIRS	High Resolution Infrared Sounder
IFOV	Instantaneous Field of View
IR	Infrared
LMID	Lockheed Martin (channel) Identification
MODIS	Moderate Resolution Imaging Spectroradiometer
MSU	Microwave Sounding Unit
NASA	National Aeronautics and Space Administration
NCEP	National Center for Environmental Prediction
NEdT	Noise Equivalent differential Temperature
NEN	Noise Equivalent Radiance
NOAA	National Oceanic and Avionics Administration
OBC	On-Board Calibrator (usually refers to onboard blackbody)
PF	Pre-flight or Protoflight
PFM	Protoflight Flight Model
PGE	Product Generation Executable
PGS	Product Generation System
POL	Polarization
POP	Popcorn Detection
PV	Photovoltaic
QA	Quality Assessment
RAD	Radiance

RADCIR	Radiation Circumvention
S/C	Spacecraft
SEM	Sensor Electronics Module
SPEC	Spectral
SRF	Spectral Response Function
SST	Sea Surface Temperature
SV	Space View
TAI	Temps Atomique International (Double Precision Floating point seconds from Jan 1, 1993)
TAP	Telemetry Analysis Program
TINT	Integration Time
TOA	Top of Atmosphere
VIS/NIR	Visible and Near Infrared